SHIP PRODUCTION COMMITTEE
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April 9, 1999
NSRP 0529
N1-93-1

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Feasibility and Economics Study of the Treatment, Recycling and Disposal of Spent Abrasives

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
National Steel and Shipbuilding Company
San Diego, California

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **09 APR 1999**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **The National Shipbuiliding Research Program Feasibility and Economics Study of the Treatment, Recycling and Disposal of Spent Abrasives**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Surface Warfare Center CD Code 2230-Design Integration Tower Bldg 192, Room 128 9500 MacArthur Blvd Bethesda, MD 20817-5700**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**94**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

DISCLAIMER

FINAL REPORT

FEASIBILITY and ECONOMICS STUDY of the TREATMENT, RECYCLING and DISPOSAL of SPENT ABRASIVES

Project N1-93-1

NSRP # 0529

National Shipbuilding Research Program

SNAME SPC Panel SP-1

March 1999

National Steel and Shipbuilding Company
Harbor Drive and 28th Street
San Diego, California 92113

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FOREWORD

This research project was conducted for the National Shipbuilding Research Program (NSRP) as a cooperative cost-shared effort between the U.S. Navy and National Steel and Shipbuilding Company (NASSCO) of San Diego, California. The Facilities and Environmental Effects Panel (SP-1) of SNAME's Ship Production Committee sponsored the project under the technical direction of Lynwood Haumschilt, Program Manager for Resource Management Panels.

The research was conducted by NASSCO and Beta Gamma Services under the direction of T. Michael Chee, Project Manager, and the final report was prepared by NASSCO.

The project team would like to acknowledge the assistance provided by members of the NASSCO Environmental Engineering staff, as well as the NASSCO Paint and Surface Preparation Department. Thanks are also extended to the many shipyards and vendors who provided information and took time from their busy schedules to complete survey forms and conduct follow-up teleconferences.

A special thank-you goes to Marinette Marine, Inc. of Sturgeon Bay, Wisconsin for providing the used coal slag abrasive sample for performance testing, as well as technical support to the project.

EXECUTIVE SUMMARY

Spent blast media represents a major volume component of shipbuilding and ship repair wastes sent to landfill disposal. As landfill disposal of solid waste becomes increasingly expensive and restrictive, it is in the best interest of shipyards to investigate alternative methods of abrasive waste management. The primary objective of this project was to study the technical feasibility and economic impacts of alternative methods of managing the waste stream produced through shipyard abrasive blasting operations.

Tasks conducted as part of the project research included:

- A survey of shipyards to determine current practices in handling and disposal of used abrasive,
- Evaluation of treatment technologies for used mineral slag abrasive,
- Laboratory and pilot scale performance testing of selected technologies, and
- Detailed economic analyses of the identified technologies to determine relative cost effectiveness.

Through surveys and other investigation, this study has identified several potential methods for shipyards to reduce abrasive waste costs and landfill disposal volumes. The methods that were shown to have both technical and economic feasibility for copper and coal slag included recycling into cement, asphalt or concrete and reuse for abrasive blasting. Cement and asphalt recycling of spent abrasive are currently practiced in various areas of the country, while a market is yet to be developed for recycling abrasive into concrete.

The economic analyses performed in this project pointed to potential cost savings for both recycling and reuse of spent slag abrasives when compared to disposal. For recycling the savings can be as much as 50%, as compared to non-hazardous landfill disposal. Reusing abrasives can result in savings of up to 130% in new material costs and 55% in disposal costs, depending on the quantity of abrasive reused on a yearly basis. For reused abrasive to meet specification requirements, processing is normally required for sizing and contamination removal. On-site thermal reclamation systems are available for shipyards. Equipment and set-up costs for such systems can be recovered in as little as two years if a sufficient quantity of spent abrasive can be generated for reuse.

1. INTRODUCTION

1.1 Background

Landfill disposal of solid waste from municipal and industrial sources is becoming increasingly expensive and restrictive. These trends will continue as existing landfills are filled to capacity and as disposal regulations become more stringent. Industries utilizing landfills for disposal of their solid wastes are not only concerned with decreased availability of disposal sites and escalating disposal costs, they may also face potential long-term environmental liabilities associated with those wastes.

The shipbuilding and ship repair industry is especially concerned with solid wastes generated by the abrasive blasting process because 'spent' blast media represents the major volume component of shipbuilding/repair wastes sent to landfill disposal. To address the economic and environmental disadvantages associated with landfill disposal of waste abrasive blast media, the National Shipbuilding Research Program (NSRP), Facilities and Environmental Panel SP-1, authorized Project N1-93-1, "Feasibility and Economics Study of the Treatment, Recycling and Disposal of Spent Abrasives". The NSRP commissioned National Steel and Shipbuilding Company (NASSCO), to perform this investigation.

1.2 Objectives

The original abstract for Project N1-93-1 stated the objective as "determine the most cost effective options available to shipyards for the treatment, reuse, recycling and disposal of spent abrasives, particularly mineral slag." The NASSCO technical proposal ultimately approved by Panel SP-1 guided this investigation. The proposal restated the abstract objective and expanded upon it with the following:

- Determine the most cost effective options available to shipyards to handle, treat, reuse, recycle or dispose of the various types of spent abrasives,
- Identify the various types of treatment technologies and recycling methods currently being used on spent abrasive and related materials,

Note: A point of terminology requires clarification here. The term 'spent' in reference to abrasives is commonly used in industry to describe abrasive blasting media, especially mineral slag, that have been used one time and are considered to be waste. In this study, it was established that mineral slag abrasives that have been used for blasting only one time (so called 'spent' abrasives), are potentially suitable for reuse. Therefore, for accuracy and clarity, the term used abrasives is substituted for 'spent' abrasives hereafter in this report.

1.3 Report Structure

The report is presented in five sections:

Section 1: Introduction, includes background information to place the project in perspective, a statement of project objectives, and an overview of the report structure;

Section 2: Study Design, describes the general approach used in this two-phase investigation;

Section 3: Findings, presents and summarizes the information and data developed by the project. Included is a discussion of the shipyard current practices survey, an overview of abrasive management options, and performance testing data;

Section 4: Discussion, is an evaluation of the technical and economic feasibility of the range of abrasive management options.

Section 5: Conclusions, reviews the significant findings of the project.

2. STUDY DESIGN

The 'used abrasive' study was performed in two distinct phases. The strategy and scope for each phase are described as follows:

2.1 Phase 1

Phase 1 was a fact-finding effort focused on development of a clear understanding of the magnitude of the used abrasive blast media issue within the shipbuilding and ship repair industry. The Phase 1 background information was seen as essential to ensuring that the project findings would ultimately be relevant to industry needs. The Phase 1 effort was also aimed at identification of the range of viable used abrasive management options. Phase 1 included the following tasks:

- Investigation of current practices used by shipyards and related industries in handling and disposal of used abrasives. Surveys were used to gather information from shipyards and abrasive vendors.
- Evaluation of treatment technologies for used abrasive or related materials. Site visits to observe treatment technology demonstrations.
- Development of an overview of potential abrasive management options and a strategy for Phase 2 testing programs.
- Report and presentation of Phase 1 findings.

2.2 Phase 2

Phase 2 emphasized evaluation of promising technologies identified during Phase 1 of the study. A best engineering judgment screening evaluation was applied to assess the technical feasibility and practicality of each technology. For selected technologies that were judged to have significant potential but were as yet unproved, the Phase 2 evaluation included laboratory and pilot scale performance testing and cost analysis development. Details of test methods used in the performance testing program are provided in Section 3.3, *Performance Testing of Selected Options*. Specific tasks performed during Phase 2 were:

- Evaluation and performance testing of technologies identified in Phase 1;

- Proposal preparation and solicitation, vendor selection, and oversight of testing programs;
- Economic analyses of the identified technologies to determine their relative cost effectiveness;
- Development of findings and recommendations, preparation of the project final report, and an oral presentation to the SP-1 Panel.

3. FINDINGS

3.1 Current Practices Survey

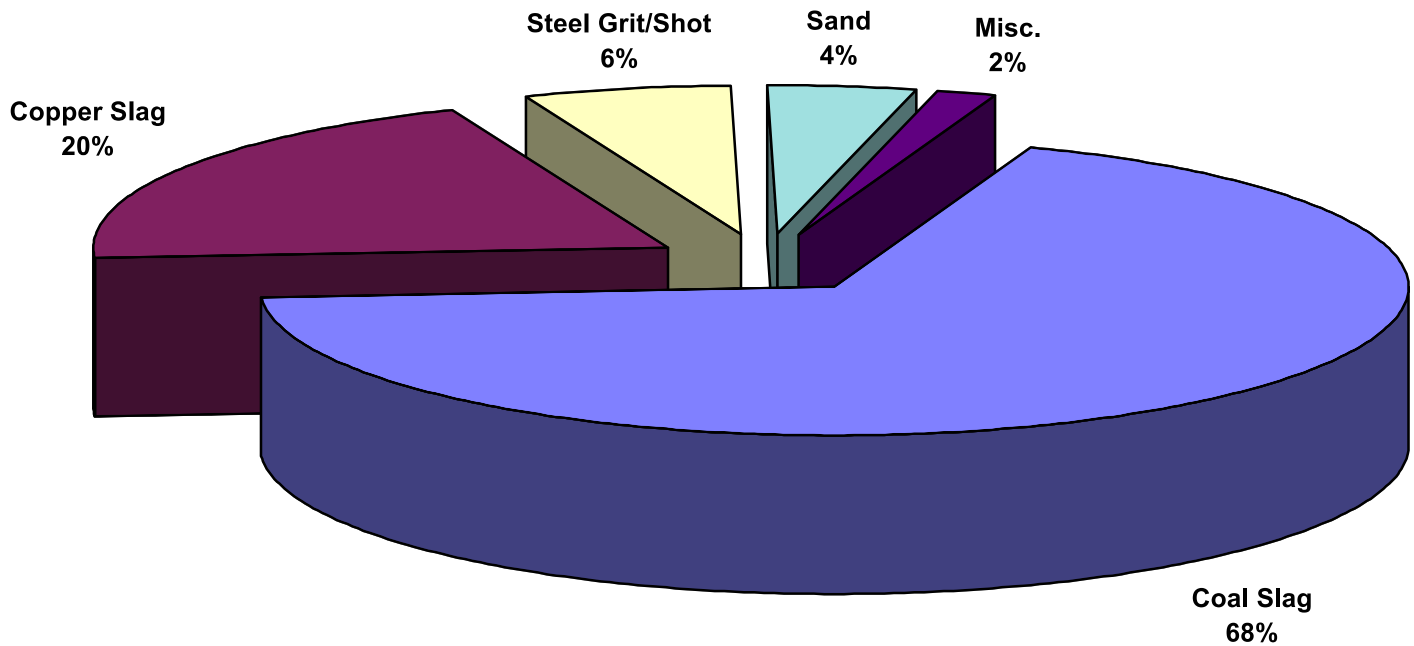
The current practices survey focused on investigation of current and potential methods for handling and disposal of used abrasives. The survey targeted shipbuilding and ship repair facilities, vendors of abrasives and equipment, and others with knowledge of abrasives and abrasive handling equipment or technologies. Information was collected through printed questionnaires and interviews (telephone and in-person).

A printed survey questionnaire was distributed to the six major shipbuilding and repair facilities. Also, to obtain a broader perspective, the questionnaire was distributed to regional representatives of several medium sized and small repair yards covering a variety of used abrasive situations throughout the country. For each facility, the questionnaire requested information on the types and quantities of abrasives in use and the management options/disposal methods and costs for each abrasive. The questionnaire was refined as the survey progressed and the final revision of the questionnaire is provided in Appendix A. When necessary, telephone interviews with shipyard personnel were conducted to follow-up on the questionnaire. Telephone and in-person interviews were also conducted with vendors, and others, to identify viable and commercially available technologies with potential application for used abrasive management. Data assembled through the questionnaire process is summarized in Appendix A-2: *Survey Results*.

Figure 1: *Abrasive Usage*, is a pie chart depiction of the relative proportions of various abrasives in use at the facilities that responded to the questionnaire. Usage is defined as tons of abrasive consumed per year. It can be seen that coal slag and copper slag abrasive comprise almost 90% of the industry consumption. Coal slag is the primary abrasive blast media used by shipyards located on the Gulf of Mexico and the Atlantic coast. Copper slag is the blast media most used by Pacific coast facilities. Steel grit or shot and sand make up about 10% of annual consumption industry-wide, with specialty abrasives (such as aluminum oxide and garnet) making up the small difference.

Shipyard Survey Results

INDUSTRY ABRASIVE MEDIA USAGE*



***Based on tons used per year as reported by 26 U.S. Shipyards and Boatyards**

Figure 1: Abrasive Usage

3.2 Management Options for Used Abrasives

Findings of the current practices surveys were reviewed and evaluated to identify potentially viable abrasive management options. All of the known options identified were categorized in terms of the three main pathways; disposal, reuse, or recycling. A schematic representation of the options identified is shown in Figure 2: *Abrasive Management Options.* (Note: Reuse indicates that the abrasive blast media is reclaimed specifically for abrasive blasting purposes, while recycling is defined as the beneficial application, other than blasting, of any component or property of the used media.)

The top of Figure 2 starts with new (virgin) abrasive media being blasted and resulting in a pile of used abrasive. At the center is the representative pile of used abrasive with arrows showing the various pathways or options available for managing the waste abrasive. The left side shows various reuse processes, possibly producing additional media for re-blasting, or producing waste (hazardous or non-hazardous) for disposal. To the right are possible recycling options, which may result in left over waste for disposal. The bottom of the figure indicates that some abrasive waste is only suitable for direct disposal, either hazardous or non-hazardous, depending on the chemical properties of the waste.

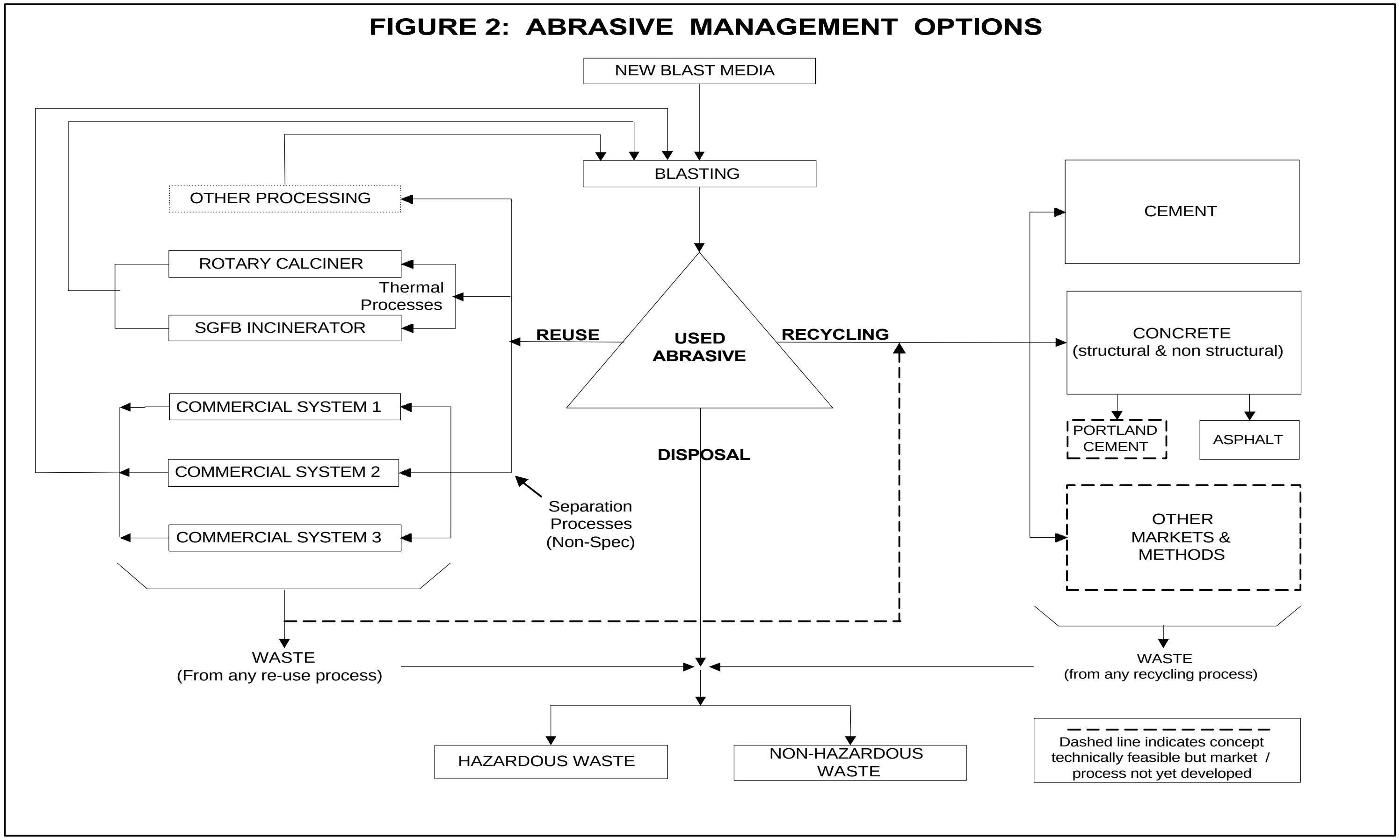


Figure 2. Abrasive Management Options

3.3 Performance Testing of Selected Options

Since several technologies were identified within both the Reuse and Recycling pathways of the Abrasive Management Options scheme (Figure 2), and because project resources were limited, it was necessary to prioritize the options to determine which should undergo actual performance testing in Phase 2 of the study. The Phase 2 testing plan was determined through an evaluation of several factors for each of the identified abrasive management options. First of all, proven technologies and those methods already established for management of abrasives were not candidates for Phase 2 performance testing. For the remaining identified options, the primary screening tool was application of best engineering judgment to evaluate technological feasibility.

Other factors that were considered within and in addition to best engineering judgment were demonstrated technical feasibility, commercial availability of the technology, relative costs, and potential regulatory issues. It was also determined that performance testing should be performed on both coal slag and copper slag abrasives to account for regional differences in mineral slag abrasive usage. The used copper slag test sample was obtained from NASSCO shipyard in San Diego, California and the coal slag sample from Marinette Marine in Sturgeon Bay, Wisconsin. All performance testing programs were conducted by qualified independent contractors and testing laboratories so that documented results could be used to address the local regulatory and market concerns of individual shipyards.

The performance testing plan consisted of recycling testing and reuse testing. Each test method is described below.

3.3.1 Recycling Testing

As defined in this study, <u>recycling</u> is the beneficial application, other than blasting, of any component or property of the used abrasive blast media. Recycling testing consisted of preliminary material characterization followed by the introduction of used abrasive as the fine aggregate component in both Portland cement concrete (PCC) and asphalt concrete (AC). Performance testing of PCC and AC was then conducted to verify conformance with industry specifications.

Recycling into concrete involves the substitution of used slag abrasive for all or part of the fine aggregate in either conventional concrete (Portland cement binder) or asphalt concrete, more commonly known as blacktop (organic emulsion binder). Concrete was selected for performance testing because, of the technically feasible recycling methods identified, the concrete option was judged to have the greatest potential for wide application throughout the shipbuilding industry. The feasibility of incorporating used abrasive materials as aggregates in Portland cement concrete or asphalt concrete mixes has been investigated previously. These attempts, particularly for Portland cement concrete, have met with mixed success. However, the use of spent copper slag as an additive in the production of asphalt concrete is an established practice in the Western U. S.

To evaluate the feasibility of using actual shipyard abrasive blast media, a systematic approach to testing and analysis under controlled laboratory conditions was designed. Early in the test program, it became apparent that the testing would best be separated into two distinct steps or phases. The objective of the initial testing phase was to analyze and characterize samples of the spent copper and coal slag abrasive. If the material analyses indicated that the materials were potentially acceptable for intended uses as aggregates in Portland cement concrete or asphalt concrete, a follow-on testing phase would be conducted to evaluate the actual performance aspects of the slag as compared to reference batches or concrete reference standards.

MATERIAL CHARACTERIZATION

Following development of the test strategy, NASSCO sent proposal requests for characterization testing to four recognized test facilities -- two in the local San Diego area, one in the Midwest, and one in the East. Based on the quality of their proposal and their reputation in the concrete industry, Construction Technology Laboratories (CTL) of Skokie, Illinois was selected to perform the initial testing phase. The approach to the analysis and characterization testing, as proposed by CTL, is outlined below.

- <u>Chemical analysis</u>, organic and inorganic, to determine the concentrations of various materials that may affect the setting of fresh concrete or durability of hardened concrete: alkalies, sulfate, carbon, chlorides, lead, magnesium, strontium, and zinc.

- Petrographic examination in accordance with ASTM C 295 (Standard Guide for Petrographic Examination of Aggregates for Concrete) will indicate the mineralogy, lithology, microstructure, and presence of coatings and deleterious material.

- Testing for reactivity with alkalies in accordance with ASTM C 1260 (Standard Test Method for Potential Alkali Reactivity of Aggregates) will indicate the tendency of the material to react with the alkalies in cement. Alkali-reactive aggregates may cause destructive expansion of concrete.

- Gradation (sieve) analysis (ASTM C 33) is necessary to determine the particle size grading of the abrasive as it compares to normal concrete sand. An unfavorable particle size grading will affect the properties of the fresh concrete, making it difficult to obtain a high quality of hardened concrete.

- Specific gravity and water absorption testing (ASTM C 128: Standard Test Method for Specific Gravity and Absorption of Fine Aggregate) will be used for calculating mix designs.

Test Results

Results from the characterization testing done by CTL are summarized as follows.

Chemical Analysis: Inorganic analysis indicated no potential problem with either copper or coal slag with respect to cement hydration. Organic analysis indicated somewhat elevated levels of elemental carbon for both slags, which could affect concrete setting time, admixture effectiveness, air content, or air void parameters. (Note: Since the used slag samples were gathered from shipyard blasting operations, paint chips and organic debris were found in both slag samples.)

Petrographic Analysis: For copper slag, the presence of paint chips and organic material may be deleterious in Portland cement concrete. Also, the presence of sulfides may react negatively with alkalies in Portland cement. For coal slag, the dense, vitreous (glassy) particles appeared suitable for use in Portland cement concrete, provided the slag is not reactive with cement alkalies. Also, the presence of organic paint fragments may interfere with normal cement hydration. (The coal slag sample contained less paint than the copper sample.)

Test for Reactivity with Alkalies (ASTMC-1260): Copper slag could not be tested for alkali reactivity because the mortar bar test specimens did not set up adequately. CTL could not explain the problem, but hypothesized that it may be due to the presence of organics (paint chips). (The copper slag was re-tested for reactivity at another lab during the performance testing phase.) Coal slag test specimens exhibited no problems in mortar bar set up. Results indicated negative reaction of coal slag with alkalies, i.e. coal slag passed this test.

Gradation: Both abrasive were graded in accordance with ASTM C-33, Standard Specifications for Concrete Aggregates. Gradation (sieve analysis) data are shown in Table 1: *Sieve Analysis Comparison*. Results for the copper slag sample indicated that the particle size distribution is very close to meeting the specification requirement. Particle sizes were within tolerance for all sieve sizes except #16 and #50, which contained slightly higher than allowable percentages of material passing.

Coal slag gradation revealed that the sample was generally finer in most sieve sizes than the specification requirement. The deviation ranged from about 10% higher for the #16 sieve to 4% higher for the #100 sieve. Both Construction Technologies Laboratory and Law Crandall, Inc deemed the overall effect of this particle size deviation on the results of concrete performance testing insignificant.

Specific Gravity and Water Absorption (ASTMC-128): Results of these tests, for both copper and coal slag, indicate that the samples are acceptable for use in concrete.

Summary of Results

Overall, results of characterization testing by CTL for the copper slag sample indicated that there is potential for retarded setting if this material was to be used in concrete due to the presence of organic matter. According to CTL, the sample tested would not be suitable for use in concrete -- either as aggregate or as a supplementary cementing material -- without further processing to neutralize or remove organic impurities.

For coal slag, overall initial indications were positive. Characterization test results showed no apparent problems for use in concrete.

SIEVE ANALYSIS COMPARISON FOR "AS RECEIVED" ABRASIVES

Results for tests conducted at three facilities:
Coreco = Coreco, Inc., Milwaukee, WI
CTL = Construction Technology Laboratory, Chicago, IL
LCI = Law Crandall, Inc., San Diego, CA

SIEVE #	CUMULATIVE % RETAINED						
	COPPER SLAG			COAL SLAG			ASTM
	Coreco	CTL	LCI	Coreco	CTL	LCI	C33
6	**0.17**	--	--	0	--	--	--
8	--	**0.17**	**1.0**	--	**0.22**	0	0 - 20
12	1.74	--	--	0.71	--	--	--
16	--	10.62	11.0	--	4.49	6.0	15 - 50
20	26.45	--	--	14.15	--	--	--
30	**49.22**	**43.31**	**42.0**	27.97	28.45	28.0	40 - 75
40	69.21	--	--	45.51	--	--	--
50	**81.54**	68.61	68.0	59.64	62.04	57.0	70 - 90
70	87.95	--	--	72.76	--	--	--
100	**93.34**	84.64	83.0	82.2	85.3	77.0	90 - 98
140	96.49	--	--	89.14	--	--	--
200	**97.97**	91.80	91.2	**94.99**	94.44	90.0	95 - 100
270	98.7	--	--	97.21	--	--	--
PAN	100.0	99.72	--	100.0	99.74	--	--

Numbers in **Bold** indicate conformance with ASTM C33 acceptable range for concrete aggregate.

Table 1. Sieve Analysis Comparison

RECYCLING PERFORMANCE TESTING

The scope and details of the recycling performance testing phase were determined after reviewing the data obtained in the characterization phase. Proposal requests for performance testing were sent to three testing facilities – Construction Technology Laboratories (CTL), who performed the characterization tests, and two local San Diego testing consultants. The best proposal was submitted by Law Crandall lnc. (LCI) of San Diego.

The recycling performance testing program recommended by LCI consisted of the following:

- Additional follow-on analysis and material characterization based on results of the initial phase, including organic impurities test and alkali reactivity retest for copper slag; and gradation, sodium soundness, sand equivalence, durability index, and mortar strength relative to Ottawa sand for both copper and coal slag;

- Portland Cement Concrete (PCC) testing, including plastic concrete testing, compressive strength, modulus of elasticity, drying shrinkage, and flexural strength;

- Asphalt Concrete (AC) testing, including Marshall stability, specific gravity, bulk unit weight, immersion compression, and film stripping.

The recycling performance testing plan is summarized in Table 2. (The test plan is discussed in detail in Appendix B: *Law Crandall, Inc. Report on Recycling Testing.*)

Table 2: CONCRETE RECYCLING PERFORMANCE TESTING PLAN

Test Name/Method	Test Standard	Copper Slag	Coal Slag
Potential Alkali Reactivity for Aggregates	ASTM C1260	Yes (re-test)	No
Deleterious Substances: Organic Impurities	ASTM C40	Yes	No
Deleterious Substances: Soundness	ASTM C88	Yes	Yes
Gradation	ASTM C136	Yes	Yes
Effect of Organic Impurities on Strength of Mortar	ASTM C87	If required	No
Durability Index	Cal. Dept. of Transportation (CalTrans) 229	Yes	Yes
Sand Equivalent	CalTrans 217	Yes	Yes
Mortar Strength Relative to Ottawa Sand	CalTrans 515	Yes	Yes
Portland Cement Concrete (PCC)			
Slump	ASTM C143	Yes	Yes
Air Content	ASTM C173	Yes	Yes
Unit Weight Yield	ASTM C138	Yes	Yes
Temperature	ASTM C1064	Yes	Yes
Setting Time	ASTM C403	Yes	Yes
Compressive Strength	ASTM C39	Yes	Yes
Modules of Elasticity	ASTM C469	Yes	Yes
Drying Shrinkage	ASTM C157	Yes	Yes
Flexural Strength	ASTM C78	Yes	Yes
Asphalt Concrete (AC)			
Marshall Stability	ASTM D1559	Yes	Yes
Specific Gravity	ASTM D2041	Yes	Yes
Bulk Unit Weight	ASTM D1188	Yes	Yes
Immersion Compression	ASTM C4867	Yes	Yes
Film Stripping	CalTrans 302	Yes	Yes

Test Results

Complete findings from the recycling performance testing phase are discussed in the report by Law Crandall, Inc., shown in Appendix A. Significant results are summarized below.

Phase 1 Follow-On Analysis: The organic impurities test for copper slag did not indicate the presence of injurious organic compounds. However, as in the initial characterization testing, the copper slag sample could not be tested for alkali reactivity due to the failure of the mortar bars to set up in a timely manner. Results of other analyses were within the normal ranges for concrete, except for mortar strength relative to Ottawa sand, which was about 20% of the sand value for copper slag and 65% for coal slag.

Portland Cement Concrete (PCC) Testing: PCC performance testing could not be run using copper slag, because the concrete test samples did not attain sufficient strength to test. Further evaluation would be required to determine the cause of the setting problem.

For coal slag, results of PCC performance testing are summarized in Table 3: *Portland Cement Concrete Test Results*. Results are compared to expected values for concrete made without slag. The comparison indicated that concrete made with coal slag had similar properties as concrete made with sand. LCI concluded that these findings support the feasibility of using coal slag in concrete. Further testing to evaluate the long-term performance of concrete made with coal slag was recommended.

Asphalt Concrete (AC) Testing: Test results for both copper and coal slag are summarized in Table 4: *Asphalt Concrete Test Results*. Four trial batches, using different asphalt contents typical of mix designs used in the San Diego area, were tested for each abrasive. Results indicated that AC batches made with both copper and coal slag had similar stability and flow as AC made with sand. According to LCI, these findings are an initial indication of the feasibility of using both copper and coal slag in asphalt concrete. Again, further testing was recommended to evaluate the long-term performance of asphalt concrete made with copper and coal slag.

Summary of Results

In summary, both copper and coal slag appear to show promise for potential use as a partial replacement for fine aggregate in asphalt concrete (AC). For Portland cement concrete (PCC), coal slag appears to be a viable replacement for sand as a fine aggregate. Since the copper slag sample tested experienced mortar and concrete setting problems, further testing with other samples would be required to determine the feasibility of using copper slag in PCC.

Table 3: PORTLAND CEMENT CONCRETE TEST RESULTS

		COAL SLAG BATCH	Approximate Expected Values for Similar Concrete Made with Washed Concrete Sand (No Slag).
Slump (ASTM C143)		6.5”	3” to 6”
Unit Weight (ASTM C138)		132.8 pcf	140 to 145 pcf
Temperature (ASTM C1064)		78° F	70° to 85° F
Setting Time (ASTM C403)		Initial Set Time: 640 minutes	120 to 240 minutes
Compressive Strength Test Data (ASTM C39)			
	7 Day	2260 psi	
	28 Day (Test 1)	3100 psi	
	28 Day (Test 2)	3020 psi	3200 to 3800 psi *
	56 Day	3360 psi	
	Modulus of Elasticity at 28 Days (ASTM C469)		
		1,955,000 psi	2,500,000 to 3,000,000 psi
	Drying Shrinkage (ASTM C157 modified)		
	7 day expansion 7 day drying 14 day drying 21 day drying 28 day drying	0.003% 0.022% 0.030% 0.035% 0.040%	0.04% to 0.05%
Flexural Strength (ASTM C78)			
	28 Day Flexural Strength - 430 psi		450 to 550 psi

* The 28 day compressive strength test data was obtained from a statistical summary of 108 production batches made with washed concrete sand (no slag); the cumulative average compressive strength was 3485 psi.

Table 4: ASPHALT CONCRETE TEST RESULTS

The proposed mix is run at different asphalt contents and the optimum asphalt content is chosen based on the results of the tests performed. The results for the mixes at different asphalt content are as follows:

Copper Slag					
Asphalt Content, % of Total Mix	*4.8*	*5.3*	*5.8*	*6.3*	**Typical Specification**
Maximum Theoretical Unit Weight	162.1	160.8	159.5	158.2	-
Voids in Mineral Aggregate (VMA)	20.8%	21.4%	21.3%	20.7%	Min. 15%
Air Voids	11.1%	10.6%	9.3%	7.5%	3 – 5 %
Corrected Marshall Stability	2250	1900	1800	1560	Min. 1800
Marshall Flow	15	15	16	17	8 – 16
Bulk Unit Weight	144.0	143.7	144.6	146.3	-
Compaction Temperature	280	280	280	280	-
Coal Slag					
Asphalt Content, % of Total Mix	*4.8*	*5.3*	*5.8*	*6.3*	**Typical Specification**
Maximum Theoretical Unit Weight	159.3	158.1	156.9	155.6	-
Voids in Mineral Aggregate (VMA)	22.1%	22.3%	21.2%	19.9%	Min. 15%
Air Voids	10.9%	10.0%	7.6%	4.9%	3 - 5 %
Corrected Marshall Stability	2400	2200	2080	1780	Min. 1800
Marshall Flow	13	14	15	16	8 - 16
Bulk Unit Weight	142.0	142.4	145.0	148.0	-
Compaction Temperature	280	280	280	280	-

3.3.2 Reuse Testing

As defined in this study, reuse means that used slag abrasive is recovered specifically for use as abrasive blast media. Reuse testing consisted of rotary calciner thermal treatment of used abrasive to achieve simultaneous contaminant removal and size classification. Performance testing was also conducted to verify conformance with Steel Structures Painting Council Specification AB1, Abrasive Blasting Media.

The concept of re-using abrasive blast media is well established for some types of abrasives, such as steel shot and garnet, but reuse has not been a standard practice for mineral slag abrasive. Conventional wisdom among many shipyard sources said that mineral slag abrasive was not suitable or cost effective for repeat blast applications. The reasons commonly given for this were that mineral slag was not of sufficient durability to survive the initial blast process and questions of potential impurities present in the used slag.

Since no hard data to support or refute the feasibility of mineral slag abrasive reuse could be located, the possibility was not eliminated. The specific questions to be answered were; 1) could significant volumes of adequate particle size distribution be available after the initial blast process to allow reuse, and, if so, 2) could this material be cleaned to the level necessary. If re-using slag abrasive could be proven practical, the potential exists for significant savings in both material and disposal costs. Figure 3 shows a sample material comparison with and without reuse. Using data from the project surveys and tests, there is potential for 130% in material savings and a 55% reduction in disposal costs. Economic analyses for several scenarios of abrasive reuse are presented in Section 4.

MATERIAL COMPARISON FOR ABRASIVE REUSE

<u>Assumptions:</u>

- New Abrasive Cost = \$50/ton
- Waste Disposal Cost = \$50/ton
- Maximum number of Reuses = 2: 80% recovered after first use, 50% after second use. (Based on slag particle size analyses.)

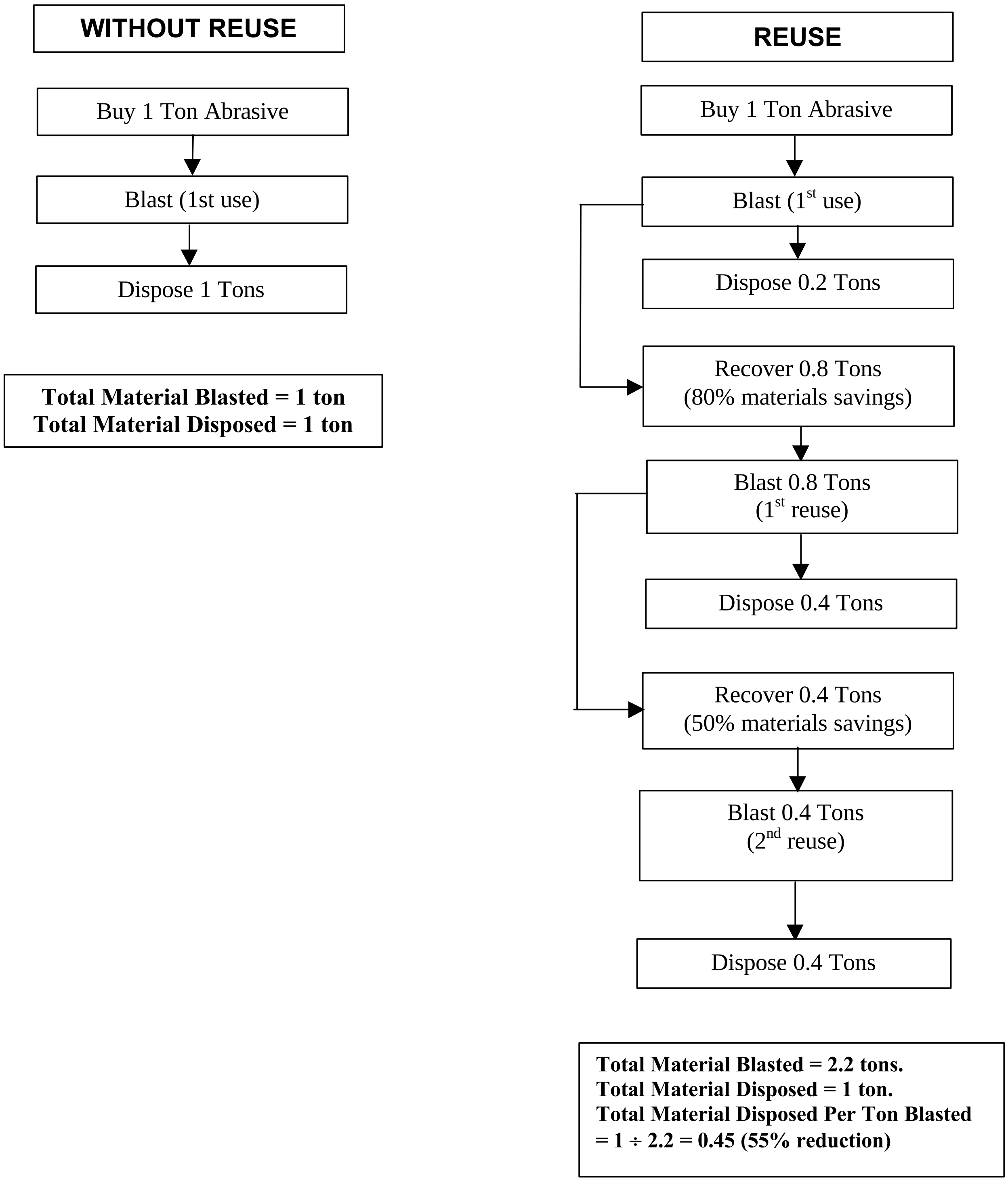


Figure 3: Sample Material Comparison for Reuse of Slag Abrasive

Early results from the material characterization step of the recycling testing program were compared with particle size distribution requirements for abrasives as listed in standard specifications. It was observed that, based on particle size alone, there were significant volumes (up to 60%) of used slag media that were potentially available for reuse. (Particles smaller than sieve size #70 (0.22 mm) were considered too small for reuse in abrasive blasting operations.)

This finding led to the decision to evaluate mineral slag reuse through a two step test program. First, foundry sand reclamation, an established thermal technology commonly used to remove organic materials and metals from sand, was applied to the copper and coal slag media. The 'cleaned' abrasive was then evaluated in terms of its physical and chemical characteristics and its performance characteristics in a controlled abrasive-blasting test. Descriptions of these test programs are summarized below.

Thermal Reclamation

The system chosen to test the thermal reclamation process for used abrasive was that supplied by Coreco, Inc. of Germantown, Wisconsin. The system has been used successfully for many years for reclamation of foundry sand, which was expected to be similar to the used copper and coal abrasive. The Coreco process can be summarized as follows:

- Raw material (used abrasive) is fed into a metered screw feeder at the top of the unit.
- Material flows through a rotary calciner (kiln) where organic matter and other contaminates are incinerated at between 1400 and 1600 degrees Fahrenheit.
- Cleaned material is screened and sized (classification) as required for the application.
- Dust and fines are collected through a cyclone and dust collection (bag house) system adjacent to the kiln.

Test Results

Samples of used copper and coal slag were processed using the Coreco reclamation system at the Coreco facility in Germantown, Wisconsin. The system was successful in removing all but trace amounts of the organic materials present in the used abrasive. The Coreco processing also removed a majority of the dust and fines from the samples. The classification screening feature of the system separated the cleaned abrasive into two portions – one greater than #70 mesh and one smaller.

REUSE PERFORMANCE TESTING

Following thermal processing of the abrasives to remove organic contaminates, testing was conducted to determine the ability of the slag to be reused for shipyard blasting operations. To this end, KTA-Tator (KTA), Incorporated of Pittsburgh, PA was contracted by NASSCO to test the performance of the abrasive samples. KTA is nationally recognized in the coatings industry as a premier consulting and testing organization. The objective of the testing by KTA would be to determine if the abrasive samples conform with the Steel Structures Painting Council's Abrasive Specification No. 1 (SSPC - AB 1). If the abrasive did meet AB 1, this would be a clear indication of the potential for re-using the cleaned slag. In addition, KTA would perform a breakdown analysis to evaluate whether the used slag had potential for another reuse.

The test program performed by KTA is summarized below. A complete description of the testing and the test results is included in Appendix C.

The following tests were performed to determine conformance of each slag with SPCC - AB 1:

- Specific gravity in accordance with ASTM C-128: "Test Method for Specific Gravity and Absorption of Fine Aggregates";
- Hardness as measured on the Mohs scale;
- Presence of water soluble contaminants in accordance with ASTM D-4940: "Test Method for Conductimetric Analysis of Water Soluble Ionic Contaminants of Blasting Abrasives";
- Oil content as determined by mixing with equal volume of water.

In addition to the AB 1 testing, KTA performed a breakdown analysis on each abrasive. The procedures for this testing are summarized below.

- Collect abrasive samples in accordance with ASTM D-75: "Method for Sampling Aggregates";
- Perform sieve analysis to establish the pre-blast particle size distribution for each abrasive;
- Perform controlled blasting of samples in a specially designed blast chamber and dust collection system;
- Perform sieve analysis to establish the post-blast particle size distribution for the abrasives.

Abrasive breakdown was calculated based on the comparison of the pre-blast versus the post-blast particle size distribution of the abrasive. Percentage breakdown was determined by finding the percent change in average particle size of each abrasive. The dust accumulated in the collection bag was weighed to determine the amount of dust generated (percentage of total sample weight). Surface profile generation testing was performed to determine conformance with AB 1.

Test Results

Results of the reuse testing performed by KTA Tator, Inc. are summarized as follows.

- Specific gravity of both copper (2.74) and coal (2.89) slag were both higher than the minimum requirement under SPCC-AB 1 (2.5);
- Hardness values for both abrasives were greater than 6 mohs, which is the minimum requirement under AB 1;
- The maximum level of water soluble contaminants (conductivity) permitted by AB 1 is 1000 microsiemens. The test result for coal slag was 235 microsiemens and for copper slag was 3500 microsiemens.
- For oil content testing, both abrasives revealed the presence of oil. No amount of oil is permitted under SSPC-AB 1, although the specification does not require that the type, quantity, color, or physical characteristics of the oil be identified.

In summary, both copper and coal abrasives passed the specific gravity and hardness tests and both failed the oil content test. Coal passed the conductivity test, but copper failed this test. Additional oil content and conductivity testing was performed on washed samples of each abrasive. Both abrasives passed this testing. The washed-abrasive testing is discussed in detail in Appendix C: *KTA-Tator Report on Reuse Testing*.

The abrasive breakdown test results indicated a breakdown rate of 42.6% for copper slag and 52.8% for coal slag. (See Appendix C for details.) Both abrasives had dust generation rates of about 10%. Also, both abrasives produced average surface profiles of nearly 4.0 mils, which meets the requirements of AB 1. These results would lead to the conclusion that no more than one reuse would be practical for both copper and coal slag without additional processing to remove fines. However, one reuse may be economically justified as a cost reduction measure in shipyards. Economics are discussed in Section 4.

4. COST ANALYSIS

This section provides cost information for the commercially viable options discussed in the previous section. By comparing this information with current practices, shipyards have a tool for determining the most cost-effective options for managing their used abrasive.

4.1 Results

In Tables 5 and 6, sample cost comparisons are presented for both of the primary abrasive included in the study, copper and coal slag. The three management options shown for each abrasive are disposal, recycling and reuse. To allow direct comparison of options, normalized costs are shown appropriate for each method: dollars per ton disposed for the disposal option; dollars per ton blasted for the recycling method; and dollars per new ton blasted for the reuse option.

For the <u>disposal</u> option (Option A), two disposal methods are listed, along with a cost range and average costs as derived from project surveys.

For the <u>recycling</u> option (Option B), the methods shown represent current practices indicated by survey responses. Cost data were derived from project surveys. (Note that only one recycling method was identified in surveys for each abrasive.)

For the <u>reuse</u> option (Option C), two methods or processes for reclaiming abrasive are shown. On-site thermal processing (C1) includes both the rotary calciner (Coreco system discussed in Section 3.3.2) and the sloping grid fluidized bed incinerator. These are commercially available systems that can be purchased and set up at a shipyard or other industrial site. Since their costs and associated material savings are similar, the thermal systems are grouped together in this analysis. Two types of commercially available separation systems (C2a & b) are also shown for the reuse option.

One other reuse method was identified, but not included in the cost comparison since, at the time of the study, was unique to one area of the Pacific Northwest. This system involves off-site reclamation of used copper slag abrasive. A vendor picks up once-used abrasive from the shipyard for a fee of $26 per ton. The abrasive is processed at

the vendor's nearby facility using a modified thermal and separation process. Clean abrasive is then resold to the shipyard for about $16 per ton less than the local cost for new abrasive. The net savings to the shipyard is about $22 per new ton blasted, assuming that the used abrasive would have been sent to a local cement kiln. This option compares favorably with the other reuse options shown in the sample cost comparison.

Cost analyses for the reuse option are more involved than the other two options, since there are more cost elements and material savings must also be considered. Cost elements used in Tables 5 and 6 are explained below:

- Processing costs for on-site reuse methods were derived from vendor furnished information, including capital and operating costs, and assume a process rate of two tons per hour (4000 tons per year) and two reuses of the abrasive. (Project testing has established a practical limit of two reuses for copper and coal slag based on particle size analysis.)

- Waste disposal costs for the reuse option are derived by dividing average non-hazardous landfill costs (Method A2) by the number of effective uses for each abrasive (See note (g) in Figure 4). Disposal costs are assumed to be equal for each reuse method, since each method produces an equal volume of waste in the form of fines and bag house dust.

- Additional on-site costs include environmental permits to operate equipment, amortized over one year.

- Total costs are the addition of process, disposal, and environmental costs.

- Material savings are determined by subtracting the reused abrasive cost per ton from the new abrasive cost. (Average new abrasive costs of $50 per ton for both copper and coal slag were based on survey results.) Material savings, like disposal costs, are the same for each reuse method, since the reuse cost, which is a function of the number of effective uses, is the same for each method.

- Net costs for reuse methods is calculated by subtracting material savings from total costs.

Tables 7 and 8 present detailed economic analyses for the reuse option, utilizing the thermal process for copper and coal slag. These analyses assume that the used abrasive entering the thermal process is non-hazardous and the abrasive waste resulting from thermal processing, in the form of bag house fines, is also non-hazardous. Three process capacities are shown, ranging from 2000 to 20,000 tons per year, which represents the range of used abrasive generated by shipyards as reported in the project survey.

Two reuse cases are presented for each abrasive, which are intended to show the economic impact of multiple reuses. Due to relatively high breakdown rates, two reuses are considered the practical limit for slag abrasive. The notes and calculations page that accompanies the tables (Figure 4) explains the derivation of the numbers in each column.

Table 9 again analyzes the thermal process, but assumes the resulting bag house fines have tested hazardous and are subject to significant hazardous waste disposal fees. For this example, only coal slag was used and the bag house fines were assumed to comprise about 5% of the total waste stream, which reflects the actual result during project testing.

Tables 10 and 11 provide sample savings and payback analyses that are intended to justify the capital expenditures associated with the thermal process for the various process capacities. Columns show savings per ton processed, savings per year, and payback period in years, including capital and operation costs. The notes and calculations page that accompanies the tables (Figure 5) explains the derivation of the numbers in each column.

Sample Cost Comparison for Copper Slag

OPTION A: DISPOSAL

DISPOSAL METHOD	COSTS ($/ton disposed)(1)	
	Range	Avg.
A1. Hazardous Waste Landfill (w/o treatment)	440 - 600	520
A2. Non-hazardous Landfill	20 - 100	55

OPTION B: RECYCLING

RECYCLING METHOD	COSTS ($/ton blasted)(1)	
	Range	Avg.
B1. Cement Kiln Feedstock	15 - 59	28
B2. Asphalt Additive (2)	N/A	N/A

OPTION C: REUSE

REUSE METHOD	COSTS ($/new ton blasted)				MAT'L SAVINGS(6)	NET COST(7)
	Proces-sing(3)	Waste Disposal(4)	Other(5)	TOTAL	($/new ton blasted)	
C1. Thermal Processing, On-site	22	25	2	49	27	22
C2.a Separation System 1	10	25	1	36	27	9
C2.b Separation System 2	13	25	1	39	27	12

Notes: (1) Costs are derived from shipyard surveys and may include sub-costs such as processing, handling, and transportation
(2) Not identified in surveys as option for this abrasive type
(3) Includes depreciated (10 year) capital and operating costs (provided by manufacturers); assumes 2 reuses and a process rate of 2 tons/hr (4000 tons/yr)
(4) Assumes fines are non-hazardous and waste volume is equal for each process [See note (g) of Figure 4]
(5) Environmental permits, amortized over one year
(6) Material savings = New abrasive cost - Reuse cost [See note (f) of Figure 4]
(7) Net cost = Total cost - Material savings

Table 5. Cost Comparison for Copper Slag

Sample Cost Comparison for Coal Slag

OPTION A: DISPOSAL

DISPOSAL METHOD	COSTS ($/ton disposed)(1)	
	Range	Avg.
A1. Hazardous Waste Landfill (w/o treatment)	350 - 490	445
A2. Non-hazardous Landfill	10 - 60	42

OPTION B: RECYCLING

RECYCLING METHOD	COSTS ($/ton blasted)(1)	
	Range	Avg.
B1. Cement Kiln Feedstock (2)	N/A	N/A
B2. Asphalt Additive	3 - 12	8

OPTION C: REUSE

REUSE METHOD	COSTS ($/new ton blasted)				Material Savings(6)	Net Cost(7)
	Proces-sing(3)	Waste Disposal(4)	Other(5)	TOTAL	($/new ton blasted)	
C1. Thermal Processing, On-site	22	21	2	45	25	20
C2.a Separation System 1	10	21	1	32	25	8
C2.b Separation System 2	13	21	1	35	25	10

Notes:
(1) Costs are derived from shipyard surveys and may include sub-costs such as processing, handling, and transportation
(2) Not identified in surveys as option for this abrasive type
(3) Includes depreciated (10 year) capital and operating costs (provided by manufacturers); assumes 2 reuses and a process rate of 2 tons/hr (4000 tons/yr)
(4) Assumes fines are non-hazardous and waste volume is equal for each process [See note (g) of Figure 4]
(5) Environmental permits, amortized over one year
(6) Material savings = New abrasive cost - Reuse cost [See note (f) of Figure 4]
(7) Net cost = Total cost - Material savings

Table 6. Cost Comparison for Coal Slag

4.2 Discussion

The sample cost comparisons in Tables 5 and 6 can be used to help shipyards determine the most cost-effective option for managing abrasive waste. Since the tables show cost ranges and averages, each shipyard should insert their actual costs as appropriate to customize the comparison for their specific situation. For example, to perform the cost comparison for coal slag (Table 6), a shipyard would insert their actual disposal costs in rows Al and A2, and their actual cost to recycle slag into asphalt in row B2.

For reuse, their actual disposal cost would be determined and actual material savings could be calculated (see note for column f in Figure 4). Using the actual data, the net costs for the various reuse methods can be determined. Then, by comparing costs for the various options, a shipyard can see which option or options have the lowest costs compared to their current practice and therefore merit further investigation.

For the example comparison in Table 6 for coal slag, the lowest costs shown are $8 per ton for both recycling into asphalt and reuse with separation system #1. Separation system #2 is a close second at $10 per ton. Based on this information, if a shipyard is not currently practicing one of these methods, cost savings could potentially be achieved by switching to one of these lower-cost methods for abrasive management.

The economic analysis for reuse of copper slag with non-hazardous waste disposal (Table 7) indicates that the total costs per new ton blasted for one reuse, including equipment depreciation and operation cost, range from about $98 for 2000 tons processed per year to $69 for 20,000 tons processed. For two reuses, the costs drop to $84 and $59, respectively. These costs compare favorably with a nominal total cost without reuse of $105 per ton blasted, including only virgin material ($50 per ton) and disposal ($55 per ton, from survey).

The costs for coal slag with non-hazardous disposal (Table 8) are similar to the copper slag costs, ranging from $92 to $57 per new ton blasted. These reuse costs can be compared to a nominal total cost without reuse of $92 per ton blasted, including material ($50 per ton) and disposal ($42 per ton, from survey). Therefore, when compared to

costs without reuse, copper slag shows potentially higher savings. Savings and payback analyses are discussed below.

Since the on-site thermal process for reuse has the highest potential capital and operating outlay, savings and payback analyses were done for the copper slag thermal reuse option assuming non-hazardous waste disposal (Table 10) and for coal slag assuming both hazardous and non-hazardous disposal of fines (Table 11). Results of the analysis indicates that, for non-hazardous disposal, the best payback (about seven months) results from reusing copper slag twice at a processing rate of 20,000 tons per year. The results for two reuses of coal slag are similar. These results point out the economy of scale for thermal processing of slag abrasive. However, most shipyards would generate less than 20,000 tons of used abrasive in a typical year.

Even when considering the smaller processing rate of 4,000 tons per year, which is a quantity generated by many large and medium sized yards, payback periods are reasonable for both cases and both abrasive, ranging from 2.2 to 3.9 years. For the smallest processing capacity of 2,000 tons per year, payback periods are higher, especially for coal slag. The payback period of 3.8 years for two reuses of copper and 5.9 years for two reuses of coal may be considered acceptable for capital investment by some yards.

When waste from the reuse process is considered hazardous, the payback economics change considerably due to the high cost of waste disposal. However, since usually only a small portion of the waste, in the form of bag house fines, requires hazardous disposal, payback may still be feasible. For two reuses of coal slag at a rate of 20,000 tons per year, the payback period is a very reasonable 14 months (See Table 11). Even at 4,000 tons per year, payback is five and a half years. It should be noted that if the volume of waste requiring hazardous disposal is higher than five or ten percent of the total waste stream, reuse equipment payback would probably not be feasible.

Economic Analysis for Reuse of Copper Slag using Thermal Processing

NON-HAZARDOUS WASTE DISPOSAL

*Case 1: One reuse; 80% reclaimed**

PROCESS CAPACITY [a]	CAPITAL COST [b]	CAPITAL COST / YR [c]	CAPITAL COST / TON [d]	OPERATION COST / TON [e]	ABRASIVE COST / TON [f]	DISPOSAL COST / TON [g]	TOTAL COST / TON [h]
1 ton/hr 2000 t/yr	$260,000	$26,000	$13.00	$9.00 (utilities) $14.40 (labor)	$27.78	$30.56	$97.74
2 tons/hr 4000 t/yr	$380,000	$38,000	$9.50	$7.00 (utilities) $7.20 (labor)	$27.78	$30.56	$83.54
5 tons/hr 20,000 t/yr	$570,000	$57,000	$2.85	$5.00 (utilities) $3.00 (labor)	$27.78	$30.56	$69.19

*Based on particle size analysis of once-used abrasive sample

*Case 2: Two reuses; 80% reclaimed first pass, 50% second pass***

PROCESS CAPACITY [a]	CAPITAL COST ($) [b]	CAPITAL COST / YR [c]	CAPITAL COST / TON [d]	OPERATION COST / TON [e]	ABRASIVE COST / TON [f]	DISPOSAL COST / TON [g]	TOTAL COST / TON [h]
1 ton/hr 2000 t/yr	$260,000	$26,000	$13.00	$9.00 (utilities) $14.40 (labor)	$22.73	$25.00	$84.13
2 tons/hr 4000 t/yr	$380,000	$38,000	$9.50	$7.00 (utilities) $7.20 (labor)	$22.73	$25.00	$71.43
5 tons/hr 20,000 t/yr	$570,000	$57,000	$2.85	$5.00 (utilities) $3.00 (labor)	$22.73	$25.00	$58.58

**Based on particle size analysis of used abrasive test

See Figure 4 for notes and calculations for each column

Table 7. Economic Analysis for Reuse of Copper Slag

Economic Analysis for Reuse of Coal Slag using Thermal Processing

NON-HAZARDOUS WASTE DISPOSAL

*<u>Case 1</u>: One reuse; 65% reclaimed**

PROCESS CAPACITY [a]	CAPITAL COST ($) [b]	CAPITAL COST / YR [c]	CAPITAL COST / TON [d]	OPERATION COST / TON [e]	ABRASIVE COST / TON [f]	DISPOSAL COST / TON [g]	TOTAL COST / TON [h]
1 ton/hr 2000 t/yr	$260,000	$26,000	$13.00	$9.00 (utilities) $14.40 (labor)	$30.30	$25.45	$92.15
2 tons/hr 4000 t/yr	$380,000	$38,000	$9.50	$7.00 (utilities) $7.20 (labor)	$30.30	$25.45	$79.45
5 tons/hr 20,000 t/yr	$570,000	$57,000	$2.85	$5.00 (utilities) $3.00 (labor)	$30.30	$25.45	$66.60

* Based on particle size analysis of once-used abrasive sample

*<u>Case 2</u>: Two reuses; 65% reclaimed first pass, 50% second pass***

PROCESS CAPACITY [a]	CAPITAL COST ($) [b]	CAPITAL COST / YR [c]	CAPITAL COST / TON [d]	OPERATION COST / TON [e]	ABRASIVE COST / TON [f]	DISPOSAL COST / TON [g]	TOTAL COST / TON [h]
1 ton/hr 2000 t/yr	$260,000	$26,000	$13.00	$9.00 (utilities) $14.40 (labor)	$25.25	$21.21	$82.86
2 tons/hr 4000 t/yr	$380,000	$38,000	$9.50	$7.00 (utilities) $7.20 (labor)	$25.25	$21.21	$70.16
5 tons/hr 20,000 t/yr	$570,000	$57,000	$2.85	$5.00 (utilities) $3.00 (labor)	$25.25	$21.21	$57.31

** Based on particle size analysis of used abrasive test

See Figure 4 for notes and calculations for each column

Table 8. Economic Analysis for Reuse of Coal Slag - Non-Hazardous Waste Disposal

Economic Analysis for Reuse of Coal Slag using Thermal Processing

HAZARDOUS WASTE DISPOSAL (FINES)

NOTE: This analysis is based on the assumption that prior to processing for reuse, abrasive waste was non-hazardous and after processing, only baghouse wastes, which make up about 5% by weight of the total waste stream, are hazardous.
[Initial disposal cost/ton = 0.95 x $42 + 0.05 x $600 = $70]

*Case 1: One reuse; 65% reclaimed**

PROCESS CAPACITY [a]	CAPITAL COST ($) [b]	CAPITAL COST / YR [c]	CAPITAL COST / TON [d]	OPERATION COST / TON [e]	ABRASIVE COST / TON [f]	DISPOSAL COST / TON [g]	TOTAL COST / TON [h]
1 ton/hr 2000 t/yr	$260,000	$26,000	$13.00	$9.00 (utilities) $14.40 (labor)	$30.30	$42.42	$109.12
2 tons/hr 4000 t/yr	$380,000	$38,000	$9.50	$7.00 (utilities) $7.20 (labor)	$30.30	$42.42	$96.42
5 tons/hr 20,000 t/yr	$570,000	$57,000	$2.85	$5.00 (utilities) $3.00 (labor)	$30.30	$42.42	$83.57

* Based on particle size analysis of once-used abrasive sample

*Case 2: Two reuses; 65% reclaimed first pass, 50% second pass***

PROCESS CAPACITY [a]	CAPITAL COST ($) [b]	CAPITAL COST / YR [c]	CAPITAL COST / TON [d]	OPERATION COST / TON [e]	ABRASIVE COST / TON [f]	DISPOSAL COST / TON [g]	TOTAL COST / TON [h]
1 ton/hr 2000 t/yr	$260,000	$26,000	$13.00	$9.00 (utilities) $14.40 (labor)	$25.25	$35.35	$97.00
2 tons/hr 4000 t/yr	$380,000	$38,000	$9.50	$7.00 (utilities) $7.20 (labor)	$25.25	$35.35	$84.30
5 tons/hr 20,000 t/yr	$570,000	$57,000	$2.85	$5.00 (utilities) $3.00 (labor)	$25.25	$35.35	$71.45

** Based on particle size analysis of used abrasive test

See Figure 4 for notes and calculations for columns

Table 9. Economic Analysis for Reuse of Coal Slag - Hazardous Waste Disposal

Notes and Calculations for Economic Analysis of Thermal Reuse Process

a. Process capacities represent a sample of several system sizes available from the manufacturer. (Other capacities are available.) Corresponding annual production outputs are calculated as follows:

1 ton/hr x 8 hr/day X 250 days/yr	= 2000 tons/yr (one shift)
2 tons/hr X " "	= 4000 tons/yr (one shift)
5 tons/hr X 16 hr/day "	= 20,000 tons/yr (two shifts)

b. Capital costs are supplied by manufacturers and include thermal processing unit and installation. Costs do not include supplemental storage or material handling equipment.

c. Cap cost/yr = Cap costs ÷ 10 yrs (Assumed amortization period)

d. Cap cost/ton = Cap costs/yr ÷ Process capacity (tons/yr)

e. Utility costs from manufacturer (projected).
Labor: 1 man @ 4 hr/shift X $30/hr ÷ process rate (Assumes that equipment needs to be attended for one half of each operational shift.)
Example, for 5 tons/hr: (4 hr/shift X 2 shifts X $30/hr) ÷ (5 tons/hr X 16 hrs) = $3.00/ton

f. Abrasive cost/ton = New abrasive cost* ÷ n (# of effective uses), where
n = 1+(1X0.8) = 1.8 for one reuse of copper slag
n = 1+(1X0.65) = 1.65 for one reuse of coal slag
n = 1+(1X0.8)+(0.8X0.5) = 2.20 for two reuses of copper slag
n = 1+(1X0.65)+(0.65X0.5) = 1.98 for two reuses of coal slag
* Assumed new abrasive cost = $50./ton for both slags

g. Disposal cost/ton = Initial disposal cost** ÷ n
** Initial disposal costs (from project surveys)
= $55./ton for copper slag, non-hazardous
= $42./ton for coal slag, non-hazardous
= $600/ton (nominal) for both slags, hazardous

h. Total cost/ton (including depreciation) = Capital cost/ton (d) + Operation cost/ton (e) + Abrasive cost/ton (f) + Disposal cost/ton (g)

Figure 4. Notes and Calculations for Economic Analysis

Payback Analysis for Reuse of Copper Slag using Thermal Processing

NON-HAZARDOUS WASTE DISPOSAL

*<u>Case 1</u>: One reuse; 80% reclaimed**

PROCESS CAPACITY [A]	SAVINGS/ TON [B]	SAVINGS/ YEAR [C]	PAYBACK PERIOD (yrs) [D]
2000 t/yr	$44.44	$88.9k	5.4
4000 t/yr	$44.44	$177.8k	3.0
20,000 t/yr	$44.44	$888.8k	0.8

* Based on particle size analysis for project abrasive sample

*<u>Case 2</u>: Two reuses; 80% reclaimed first pass, 50% second pass***

PROCESS CAPACITY [A]	SAVINGS/ TON [B]	SAVINGS/ YEAR [C]	PAYBACK PERIOD (yrs) [D]
2000 t/yr	$54.54	$109.1k	3.8
4000 t/yr	$54.54	$218.2k	2.3
20,000 t/yr	$54.54	$1,090.8k	0.6

** Based on particle size analysis of used abrasive test

See Figure 5 for notes and calculations for each column

Table 10. Payback Analysis for Reuse of Copper Slag

Payback Analysis for Reuse of Coal Slag using Thermal Processing

NON-HAZARDOUS WASTE DISPOSAL

Case 1: *One reuse; 65% reclaimed**

PROCESS CAPACITY [A]	SAVINGS/ TON [B]	SAVINGS/ YEAR [C]	PAYBACK PERIOD (yrs) [D]
2000 t/yr	$39.40	$78.8K	6.8
4000 t/yr	$39.40	$157.6K	3.6
20,000 t/yr	$39.40	$788.0K	0.9

Case 2: *Two reuses; 80% reclaimed first pass, 50% second pass***

PROCESS CAPACITY [A]	SAVINGS/ TON [B]	SAVINGS/ YEAR [C]	PAYBACK PERIOD (yrs) [D]
2000 t/yr	$49.50	$99.0K	4.4
4000 t/yr	$49.50	$198.0K	2.6
20,000 t/yr	$49.50	$990.0K	0.7

HAZARDOUS WASTE DISPOSAL (FINES)

PROCESS CAPACITY [A]	SAVINGS/ TON [B]	SAVINGS/ YEAR [C]	PAYBACK PERIOD (yrs) [D]
2000 t/yr	$19.28	$38,560	n/a
4000 t/yr	$19.28	$77,120	18.7
20,000 t/yr	$19.28	$385,600	2.5

PROCESS CAPACITY [A]	SAVINGS/ TON [B]	SAVINGS/ YEAR [C]	PAYBACK PERIOD (yrs) [D]
2000 t/yr	$31.40	$62,800	16.2
4000 t/yr	$31.40	$125,600	5.5
20,000 t/yr	$31.40	$628,000	1.2

* Based on particle size analysis of abrasive sample

** Based on particle size analysis of project abrasive test

See Figure 5 for notes and calculations for each column

Table 11. Payback Analysis for Reuse of Coal Slag

Notes and Calculations for Payback Analysis for Thermal Reuse Process

A. Process capacities represent a sample of several system sizes available from the manufacturer. (Other capacities are available.) Corresponding annual production outputs are calculated as follows:

1 ton/hr X 8 hr/day X 250 days/yr	= 2000 tons/yr (one shift)
2 tons/hr X " "	= 4000 tons/yr (one shift)
5 tons/hr X 16 hr/day "	= 20,000 tons/yr (two shifts)

B. Savings/ton = [Abrasive + Disposal cost without reuse]
- [Abrasive + Disposal cost with reuse]*

Example for copper slag @ 2000 tons/yr with non-hazardous disposal for one reuse:

[$50/ton + $55/ton] - [$27.78/ton + $30.56/ton] = $46.67/ton

C. Savings/year = Savings/ton (B) X tons processed/year (A)

D. Payback Period (in years) = Capital cost (b*) ÷ [Savings/yr (C) - Operation cost/yr (e X a)*]

Example for copper slag @ 2000 tons/yr with non-hazardous disposal for one reuse:

$260,000 ÷ [$93,340 - ($23.40/ton X 2000 tons/yr)] = 5.6 years

*from Economic Analysis, Tables 7 and 8

Figure 5. Notes and Calculations for Payback Analysis

5. CONCLUSIONS

Significant findings from the research conducted in this project can be summarized as follows:

A survey of current practices related to used abrasive management methods at large and small shipyards revealed that, due to availability, copper slag is the abrasive of choice in the West, while coal slag is used almost exclusively in the East. Most large yards use a variety of abrasives, depending on the application. Large yards generate from 9,000 to 20,000 tons of abrasive waste a year and spend an average of $30 to $40 a ton to dispose or recycle the used abrasive. Recycling is the most common route for used copper slag, while landfill disposal was common for coal and sand.

Based on survey results, several options were identified for managing abrasives under the categories of recycling, reuse and disposal. For recycling, the primary options are using ground-spent slag as an additive in cement production and incorporating into concrete as an aggregate. Reuse options include thermal processing to bring reused abrasive into industry specification and separation processing, which prepares the material for reuse but not necessarily to specification conformance. Two disposal options were identified: sanitary landfill disposal for non-hazardous materials and hazardous or special landfill for hazardous materials.

Several potential options for both copper and coal slag were chosen for additional feasibility evaluation and performance testing. Based on the test results for the sample selected for the project, coal slag appears to be feasible for recycling into concrete (both Portland cement and asphalt) and also appears viable for reuse (one time only). The caveat for reuse is that the abrasive to be reused must be free of oil contamination to meet the specification requirements of the Steel Structures Paint Council.

The copper slag sample selected for testing happened to contain a significant amount of organic contamination (probably paint residue), which prevented the Portland cement concrete (PCC) strength testing from being performed. However, the sample did appear viable for recycling as a fine aggregate in asphalt concrete. (The testing laboratory conjectured that a cleaner copper slag sample would have been suitable for

PCC recycling, although additional testing would have been required to confirm this opinion.) Copper slag, like coal, appears viable for one reuse in blasting operations, with the same caveat regarding oil contamination.

From an economic perspective, cost savings are achievable for copper and coal slag abrasive for both the recycling and reuse options, when compared to the disposal option. The sample analyses performed in the project show potential savings of up to $34 per ton blasted for recycling and $50 per ton blasted for reuse. On-site thermal processing for reuse requires capital investment and operation costs. The payback period for a yard generating about 4,000 tons of coal slag waste per year would be about two and a half years, assuming two reuse cycles. (If the waste generated is considered hazardous, the economics change considerably.)

Although abrasive reuse has the potential for greater savings, most yards could benefit from the less complex option of recycling non-hazardous waste abrasive into Portland cement concrete or asphalt concrete. Recycling slag as a cement kiln additive or into asphalt are established practices in some areas of the country. Where these options are not available, shipyards may wish to contact local concrete manufacturers or distributors and regulatory agencies to investigate the feasibility of the concrete recycling method in their area.

APPENDIX A

Shipyard Survey

APPENDIX A-1
SURVEY FORM

To: SHIPYARD

From: National Steel & Shipbuilding Company, Environmental Engineering

Subject: Shipyard Survey for National Shipbuilding Research Program (NSRP), Panel SP-1, Project N1-93-1: Feasibility and Economics Study of the Treatment, Recycling and Disposal of Spent Abrasives.

Enclosed is a survey form developed to support Phase 1 of the subject project. The project goal is to evaluate options for managing spent abrasives generated by the shipbuilding and ship repair industry. The project is being performed in two phases. Phase 1, Preliminary Research, is in progress and is focusing on identification of spent abrasive management practices throughout the industry. Phase 2, Testing and Recommendations, will involve analysis of spent abrasive management options identified during Phase 1. The project will conclude with a written report and a presentation of findings at the NSRP Panel meeting.

Your participation in the "Spent Abrasives" project would be appreciated. Please assist us by filling out the enclosed survey and returning the forms to NASSCO at your earliest convenience. We have attempted to keep the survey simple so that it can be completed quickly. An example of a completed survey form is also enclosed to help guide your efforts. In some cases, your abrasive blasting operations may be performed offsite or by subcontractors. Please include information from these operations in your survey to the extent possible.

We are confident that, with your help, the "Spent Abrasives" study will yield beneficial results for the shipbuilding industry and its supporting industries. Questions about the survey or the project can be directed to Barry Graham at (619) 544-8882; FAX (619) 232-6411.

Thanks again for your cooperation.

Barry Graham

NATIONAL SHIPBUILDING RESEARCH PROGRAM
SHIPYARD SURVEY FORM

Project N1-93-1: Feasibility and Economics Study of the Treatment, Recycling and Disposal of Spent Abrasives (Phase 1, Preliminary Research)

INSTRUCTIONS: Please answer all survey questions. Fax or mail the completed survey to:

NASSCO
ATTN: Barry Graham
Environmental Engineering, M/S 22-A
P.O. Box 85278
San Diego, California 92186-5278
FAX 619/232-6411

1. FACIILITY IDENTIFICATION

Facility Name ____________________
Street Address ____________________
City, State ____________________
Zip Code ____________________
Contact Person ____________________
Title ____________________
Telephone ____________________
Fax ____________________

2. ENVIRONMENTAL REGULATION

Indicate the Environmental Regulation classification(s) assigned to your spent abrasive wastes and the regulatory agency(ies) responsible for solid/hazardous waste enforcement.

Classification	Agency
≤ RCRA Hazardous Waste	(Federal) EPA, Region ____________
≤ State Only Hazardous Waste	(State, Regional) ____________
≤ Non-Hazardous Waste	(Local, Other) ____________

3. SPENT ABRASIVE PROFILE

a. Indicate which coating types might typically be found in any spent abrasives generated by your operations. (Check applicable boxes and provide product names.)

≤ Anti-Corrosive/Anti-Fouling Coatings ____________
≤ Epoxies ____________
≤ Enamels ____________
≤ Zinc-Rich Coatings ____________
≤ Urethanes ____________
≤ Others ____________

b. Are analytical results (chemical/physical data) available for spent abrasives generated by your operations? ≤ YES ≤ NO

4. ABRASIVE BLASTING MANAGEMENT PRACTICES

Complete Table 1 - Spent Abrasive Management Practices, for all operation(s) that generate spent abrasive blast media. Operations may be performed on-site or off-site by employees and/or subcontractors. (Make additional copies of Table 1 as needed.)

(Make additional copies of this page as needed.)

TABLE 1 - SPENT ABRASIVE MANAGEMENT PRACTICES

FACILITY NAME ____________________________________

Blast Media__________________ Product Name______________________________

RECYCLING	DISPOSAL
(YES) (NO)	(YES) (NO)
On Site----------------------------------≤ ≤	Hazardous Waste---------------------------≤ ≤
Method _______________________________	Quantity____________________________(Tons/Yr)
Pre-Treatment Process ___________________	Pre-Treatment Process _____________________
Processing Cost____________________($/Ton)	Disposal Method ___________________________
	Disposal Cost__________________________($/Ton)
(YES) (NO)	(YES) (NO)
Off Site ---------------------------------≤ ≤	Non Hazardous Waste-----------------------≤ ≤
Quantity________________________(Tons/Yr)	Quantity____________________________(Tons/Yr)
Method _______________________________	Pre-Treatment Process ______________________
Pre-Treatment Process ___________________	Disposal Method __________________________
Processing Cost____________________($/Ton)	Disposal Cost__________________________($/Ton)
Other Recycling Method________________________	Other Disposal Method
Quantity________________________(Tons/Yr)	Quantity____________________________(Tons/Yr)
Pre-Treatment Process ___________________	Pre-Treatment Process _______________________
Processing Cost____________________($/Ton)	Disposal Cost_________________________($/Ton)

Please describe your spent abrasive management practices if other than recycling or disposal.

Blast Media__________________ Product Name____________________________

RECYCLING	DISPOSAL
(YES) (NO)	(YES) (NO)
On Site----------------------------------≤ ≤	Hazardous Waste---------------------------≤ ≤
Method _______________________________	Quantity____________________________(Tons/Yr)
Pre-Treatment Process ___________________	Pre-Treatment Process _____________________
Processing Cost____________________($/Ton)	Disposal Method ___________________________
	Disposal Cost__________________________($/Ton)
(YES) (NO)	(YES) (NO)
Off Site ---------------------------------≤ ≤	Non Hazardous Waste-----------------------≤ ≤
Quantity________________________(Tons/Yr)	Quantity____________________________(Tons/Yr)
Method _______________________________	Pre-Treatment Process ______________________
Pre-Treatment Process ___________________	Disposal Method __________________________
Processing Cost____________________($/Ton)	Disposal Cost__________________________($/Ton)
Other Recycling Method________________________	Other Disposal Method
Quantity________________________(Tons/Yr)	Quantity____________________________(Tons/Yr)
Pre-Treatment Process ___________________	Pre-Treatment Process _______________________
Processing Cost____________________($/Ton)	Disposal Cost_________________________($/Ton)

APPENDIX A-2
SURVEY RESULTS

Approximately 60 surveys were sent to new construction and repair shipyards of various sizes across the country. 26 yards responded (about 50%) – six large yards and 20 small and medium yards. (See *List of Shipyards Responding to Survey* at the end of this Appendix.)

Responses to the shipyard survey are presented in table format on the following pages. The responses are grouped by abrasive type used by each yard: copper slag, coal slag, and other, which includes sand, aluminum oxide, steel grit or shot, garnet and nickel slag. For anonymity, a code is used in place of the actual shipyard name. The code indicates the geographic location of the shipyard as follows:

NE	Northeast United States
SE	Southeast
NW	Northwest
SW	Southwest
M	Midwest (Great Lakes)

Significant survey results can be summarized as follows:

- The most commonly used abrasives are coal slag and copper slag. Coal slag is used exclusively in the East by eleven yards; Copper slag is used exclusively in the West by eleven yards.

- Other abrasives such as sand, aluminum oxide and steel grit or shot are used in various parts of the country. Most large yards use a variety of abrasives, depending on the application.

- The quantity of abrasive waste generated by large yards ranged from 9,000 to 20,000 tons/year. For small and medium yards the range was from several hundred to about 4,000 tons/year.

- For coal slag, about 2/3 of the yards reported that a majority of their abrasive waste was disposed into non-hazardous landfills at an average cost of about $40 per ton. The other yards recycled most of their waste into asphalt or cement at an average cost of under $10 per ton, with a small amount going to landfill.

- For copper slag, almost all yards reported that a majority of their abrasive waste was sent to a cement company to be recycled as a cement kiln additive at an average cost of about $30 per ton. One yard reported recycling their abrasive into a road bed compound at no cost to them.

- For yards using sand as abrasive, the most common disposal method was non-hazardous landfill at an average cost of about $30 per ton. One yard recycles sand as an asphalt additive at a cost of $60 per ton.

- Eleven yards reported using steel grit or shot. In all cases, the abrasive was reused several times and the resulting waste fines, which were usually considered hazardous waste, were disposed in landfills at cost of from $200 to $500 per ton.

- Aluminum oxide and garnet abrasives were used by six yards. About half reported reusing the abrasives and the others recycled their abrasive waste into asphalt or cement at an average cost of about $15 per ton.

SHIPYARD SURVEY RESPONSES

Abrasive Media Type: COAL SLAG

Ship-yard Code	Waste Quantity (tons/yr)	RECYCLING		DISPOSAL		
		Method	Cost ($/ton)	Method	Quantity (tons/yr)	Cost ($/ton)
NE1	20,000	Asphalt additive	3	Non-Haz LandFill	200	40
NE2	1200	Asphalt additive	not/ reported	Haz LF (Paint Dust) NHLF	5 50	940 n/r
NE3	348	Asphalt additive	9.40	'Special' LF	n/r	56
NE4	n/r	Not/Applicable	N/A	NHLF	1547	n/r
SE1	4500	Asph / Cem. kiln - Conc. slurry (test)	0 - 12 0	N/A	N/A	N/A
SE2	10,000	N/A	N/A	NHLF	10,000	30
SE3	n/r	N/A	N/A	HLF NHLF	20 40	350 75
SE4	n/r	N/A	N/A	NHLF	1800	10 -12
SE5	n/r	N/A	N/A	NHLF	2800	40
SE6	n/r	N/A	N/A	NHLF	5000	50 - 60
SE7	n/r	N/A	N/A	NHLF	2579	30

Abrasive Media Type: COPPER SLAG

NW1	2500	Reuse (Classification)	8 - 12	HLF	25	600
	3320	Cement Kiln Additive (CKA)	26	N/A	N/A	N/A
NW2	600	CKA	20	N/A	N/A	N/A
NW3	960	CKA	16	N/A	N/A	N/A
NW4	20,000	Reuse	30	NHLF	10,000	20
NW5	n/r	CKA	20	N/A	N/A	N/A
NW6	n/r	CKA	59	N/A	N/A	N/A
SW1	2000	CKA	200*	N/A	N/A	N/A
SW2	3000	CKA	19	N/A	N/A	N/A
SW3	n/r	CKA	15	HLF	100	440
SW4	188	Road Bed	0	N/A	N/A	N/A
SW5	9000	CKA	50	N/A	N/A	N/A

* includes environmental testing fees n/r = not reported N/A = Not Applicable
NHLF = Non-hazardous Landfill HLF = Hazardous Landfill

Abrasive Media Type: OTHER

Media	Ship-yard Code	Waste Quantity (tons/yr)	RECYCLING		DISPOSAL		
			Method	Cost ($/ton)	Method	Quantity (tons/yr)	Cost ($/ton)
SAND	M1	n/r	N/A	N/A	HLF NHLF	0.2 50	250 35
	NE5	64	N/A	N/A	HLF NHLF	5 59	500 10
	SE3	n/r	N/A	N/A	HLF NHLF	40 280	300 70
	SE4	n/r	N/A	N/A	NHLF	900	10
	SE6	n/r	N/A	N/A	NHLF	1000	50 - 60
	SE8	350	Asphalt additive	60	NHLF	250	10
ALUM-INUM OXIDE	NE3	133	Reuse	30	Special LF	n/r	56
	SW1	25	Reuse	n/r	HLF	10	400
	SW3	13	CKA	15	HLF	3	440
	SW5	200	Alum. smelting	0	HLF	100	100
	SE6	n/r	Reuse	n/r	NHLF	200	50 - 60
	SE9	25	N/A	N/A	NHLF	25	600
STEEL GRIT/ SHOT	NE3	234	Reuse	25	Special L/F	113	56
	NW1	1310	Reuse	25	NHLF	1310	450
	NW3	n/r	Reuse	n/r	N/A	N/A	N/A
	NW5	25	Reuse	n/r	HLF	50	200
	SW1	50	Reuse	n/r	HLF	20	400
	SW3	n/r	Reuse	n/r	HLF	10	500
	SW4	n/r	Reuse	n/r	HLF NHLF	27 200	1040 700
	SW5	120	Reuse CKA	n/r 50	N/A	N/A	N/A
	SE2	n/r	Reuse	n/r	NHLF	500	15
	SE6	n/r	Reuse	n/r	NHLF	600	50-60
	SE7	n/r	Reuse	n/r	NHLF	11	80
GARNET	NE3	n/r	Asphalt Additive	9.40	Special LF	n/r	56
	NW1	25	Reuse	5	NHLF	10	50
	SW1	10	N/A	N/A	HLF	10	400
	SW2	n/r	Reuse	n/r	NHLF	10-15	100-150
	SW3	7	CKA	20	HLF	2	440
	SW4	56	Road Bed	n/r	N/A	N/A	N/A
NICKEL	SW1	400	CKA	200*	N/A	N/A	N/A

List of Shipyards Responding to Survey

Northeast	
NORSHIPCO	Norfolk, VA 23501
US Coast Guard Yard, Baltimore	Curtis Bay, MD 21226
Bath Iron Works	Bath, ME 04530
Philadelphia Naval Shipyard	Philadelphia, PA 19112
General Ship Repair	Baltimore, MD 21230
Southeast	
Atlantic Dry Dock, Jacksonville	Jacksonville, FL 32228
Atlantic Marine, Mobile	Mobile, AL 36601
Southwest Shipyard (Southwestern Barge)	Channelview, TX 77530
Trinity Marine	Port Allen, LA 70767
Bollinger Quick Repair	Harvey, LA 70059
Ingalls Shipyard	Pascagoula, MS 39567
Avondale Shipyard	New Orleans, LA 70150
Newpark Shipbuilding	Houston, TX 77120
Textron Marine	New Orleans, LA 70127
Northwest	
Cascade General	Portland, OR 97208
Tacoma Boat Building Co	Tacoma, WA 98442
Marco Shipyard	Seattle, WA 98199
Sand Products	Portland, OR
Trident Refit	Bangor, WA
Puget Sound Naval Shipyard	Bremerton, WA 98314
Southwest	
Mare Island Naval Shipyard	Vallejo, CA 94592
Southwest Marine	San Diego, CA 92113
Long Beach Naval Shipyard	Long Beach, CA 90822
Pearl Harbor Naval Shipyard	Pearl Harbor, HI 96860
NASSCO	San Diego, CA 92113
Midwest	
Bay Shipbuilding Corp.	Sturgeon Bay, WI 54235

APPENDIX B

Law Crandall, Inc.

Report on Recycling Testing

LAW/CRANDALL, INC.

ENGINEERING AND ENVIRONMENTAL SERVICES

January 15 1997

Mr. Les Hansen
NASSCO Environmental
National Steel & Shipbuilding Co.
Harbor Drive & 28th Street
P.O. Box 85279 MS-22A
San Diego, California 92186-5278

Subject: **Test Information**
Copper and Coal Slag Testing
Feasibility and Economic Study of the Treatment,
Recycling and Disposal of Spent Abrasives
Law/Crandall Job No. 70341-6-0176

Dear Mr. Hansen:

In accordance with our proposal dated July 9, 1996 we have performed testing of the copper and coal slag samples that were submitted to our laboratory. The copper slag was submitted by NASSCO in San Diego, California on July 24, 1996. The coal slag was submitted by Marinette Marine Corporation of Marinette, Wisconsin on August 18, 1996. The purpose of our work was to provide laboratory testing to aid NASSCO in their feasibility study for a use for the spent abrasives. Our work included two phases; phase 1 material characterization, and phase 2 performance testing.

The results contained in this report do not constitute or imply approval of the material for use in construction materials, the results are presented as information only. Our professional services have been performed using that degree of care and skill ordinarily exercised, under similar circumstances, by reputable construction materials consultants practicing this or similar localities. No other warranty, express or implied, is made as to the professional advice included in this report.

We do not know the specific chemical constituents of the slag material submitted to us for testing. It is our understanding that the slag material is used for abrasive blasting of painted surfaces and the specific chemical constituents may vary depending on the paint blasting residue. We do not know how representative the test samples will be of spent abrasive materials from future abrasive blasting operations.

Further testing will be required to evaluate the durability of concrete and asphalt mixtures made with these materials.

Test Results

Phase 1 - Material Characterization

A series of tests were performed to evaluate some general characteristics of the slag material. The results from the tests performed were intended to help provide an initial indication as to whether or not it might be feasible to use the slag materials in portland cement concrete or asphalt concrete. The following tests were performed as part of the phase 1 testing.

Organic Impurities - The purpose of this test is to evaluate the potential of a fine aggregate to contain organic compounds that could be injurious to portland cement concrete.

Gradation - The purpose of this test is to evaluate the particle size distribution of the aggregate. Particle size distribution is important when determining mix proportions and characteristics of the final product and conformance with standard specifications.

Sodium Soundness - This test method covers the testing of aggregates to estimate their soundness when subjected to weathering action in concrete.

Sand Equivalent - The purpose of this test is to provide a measure of the relative proportions of detrimental fine dust or clay-like material in fine aggregates.

Durability Index - This test provides a measure of the fine aggregates' relative resistance to producing clay size fines when subjected to prescribed methods of interparticle abrasion in the presence of water.

Mortar strength relative to Ottawa sand- This test is for the purpose of determining the compressive strength developed by mortar using a given concrete sand in relation to that developed by mortar using Ottawa sand and indirectly measures the concrete-making properties of the sand being tested.

Test Results

Test	Copper Slag	Coal Slag
Organic Impurities (ASTM C40)	*Lighter than color standard #3	Not Tested

*If the color of the supernatant liquid is darker than that of the reference standard #3, the fine aggregate is considered to possibly contain injurious organic compounds.

The following table presents test results from the copper and coal slags and compares the test results to standards from the American Society for Testing and Materials (ASTM), Standard Specifications for Public Works Construction (SSPWC), and the State of California Department of Transportation (Caltrans).

Test	Copper Slag	Coal Slag	ASTM C-33	SSPWC	CALTRANS
Gradation (ASTM C136) Sieve Size	% Passing	% Passing			
3/8"	100	100	100	100	-
#4	100	100	95-100	95-100	-
#8	99	100	80-100	70-90	-
#16	89	94	50-85	55-75	-
#30	58	72	25-60	30-50	-
#50	32	43	10-30	10-25	-
#100	17	23	2-10	2-10	-
#200	8.8	10		0-5	-
Sodium Soundness (ASTM C88) weighted % lost	5%	3%	10% max.	10% max.	-
Sand Equivalent (CAL 217)	79	78	-	70 min.	75 min.
Durability Index (CAL 229)	88	84	-	-	-
Mortor Strength Relative (CAL 515) **to Ottawa Sand**	*20%	*65%	-	100% min.	95% min.

* Compressive strength of copper slag mortar cubes= 1630 psi
Compressive strength of coal slag mortar cubes= 5740 psi
Compressive strength of reference mortar cubes= 9400 psi.

Discussion

The standard test for potential alkali reactivity of aggregates (ASTM C1260) was to be run on the copper slag. This test was started but results could not be obtained because the test bars did not set up. This is discussed further in the portland cement concrete trial batch section of this report.

The slag materials contained a higher percentage of material passing the finer sieves (sieve sizes 16 and smaller) than most specifications allow for concrete aggregate. This higher fines content can result in a small decrease in compressive strength and can significantly increase the water demand which will decrease the strength and durability and increase the shrinkage of concrete.

Phase 2 - Performance Testing

The purpose of the phase 2 testing was to measure specific properties of portland cement concrete and asphalt cement concrete mixes made using the spent abrasives as the fine aggregate and local San Diego area crushed rock as the coarse aggregate.

Portland Cement Concrete Testing

Two portland cement concrete trial batches were mixed. One batch contained copper slag as the fine aggregate and one batch contained coal slag as the fine aggregate. The mix design weights were calculated based on the absolute volume method. The mix weights for a 1 cubic yard batch are as follows:

Copper Slag Batch

Material	Weight per cubic yard of concrete
Copper Slag	1580 pounds
1" X #4 coarse aggregate	1952 pounds
Cement	493 pounds
Water	325 pounds

*Admixture: Master Builders 322N- 19.72 ounces per cubic yard of concrete

Coal Slag Batch

Material	Weight per cubic yard of concrete
Coal slag	1474 pounds
1" X #4 coarse aggregate	1811 pounds
Cement	493 pounds
Water	325 pounds

*Admixture: Master Builders 322N- 19.72 ounces per cubic yard of concrete

* Master Builders 322N is a water reducing admixture conforming to the requirements for ASTM C494 type A water reducing admixtures. Water reducing admixtures are typically used in the majority of concrete mixes to reduce the required amount of water or to improve workability.

The testing of the trial batch concrete was performed to evaluate the general characteristics of the plastic (fresh) concrete and the hardened concrete. The trial batches were 2.5 cubic feet. The results from the tests performed were intended to help provide an initial indication as to whether or not it might be feasible to use the slag materials in portland cement concrete.

The mix design that was used was based on a standard production mix design. The production mix design used washed concrete sand as the fine aggregate and did not contain slag. The compressive strength data for the standard production mix design is presented for general comparison to the trial

batch results. To more accurately evaluate the effects of slag on compressive strength, a laboratory reference batch not containing slag should be mixed to compare to future trial batches.

The results of the trial batches are as follows:		Approximate Expected Values for Similar Concrete Made with Washed Concrete Sand (No Slag):
Coal Slag Batch		
Slump (ASTM C143)	6 1/2"	3" to 6"
Unit Weight (ASTM C138)	132.8 pcf	140 to 145 pcf
Temperature (ASTM C1064)	78° F	70 to 85° F
Setting Time (ASTM C403)	Initial Set Time: 640 min	120 to 240 min
Compressive Strength Test Data (ASTM C39)		
7 Day	2260 psi	
28 Day (Test 1)	3100 psi	
28 Day (Test 2)	3020 psi	*28 Day 3200 to 3800 psi
56 Day	3360 psi	
Modulus of Elasticity at 28 days (ASTM C469)	1,955,000 psi	2,500,000 to 3,000,000 psi
Drying Shrinkage (ASTM C157 *modified) * As modified by the SEA report "Supplementary Recommendations For Control of Shrinkage of Concrete, May 1978.		
7 day expansion	0.003%	
7 day drying	0.022%	
14 day drying	0.030%	
21 day drying	0.035%	
28 day drying	0.040%	0.04% to 0.05%
Flexural Strength (ASTM C78)		
28 Day Flexural Strength - 430 psi		450 to 550 psi

*The 28 day compressive strength test data was obtained from a statistical summary from 108 production batches made with washed concrete sand (no slag), the cumulative average compressive strength was 3485 psi

Copper Slag Batch

The Copper Slag Batch did not set up for approximately 1 week after batching. While the plastic concrete had the same general properties as concrete made with washed concrete sand, approximately 24 hours after batching the concrete was still soft and had not obtained initial set as determined by ASTM C403. The concrete samples were allowed to sit until they had hardened enough to strip. The samples were stripped 7 days after batching. Due to the time required before the samples could be stripped, the remainder of the testing was not performed.

The properties of the plastic (fresh) concrete are as follows.

Slump (ASTM C143)	7"
Unit Weight (ASTM C138)	146.6 pcf
Temperature (ASTM C1064)	75 degrees F
Setting Time (ASTM C403)	Initial Set Time: About 1 week

Discussion

Copper Slag

The concrete made with copper slag didn't obtain initial set for approximately 1 week as determined by ASTM C403 which evaluates time of setting by measuring the ability of the mortar to resist penetration. The setting and eventual hardening of concrete is due to a chemical reaction between the cement and water which is called hydration. Water must be present for hydration to continue. The indication of initial set obtained after 1 week may be somewhat due to de-hydration, similar to a drying soil water (mud) mixture. The concrete samples did obtain enough strength to be removed from their molds without losing their shape after approximately 1 week. A further chemical investigation into the cause of the lack of set of the concrete made with copper slag would be required to evaluate the impacts on lack of concrete set. During our review of chemical data supplied on the material safety data sheets and the report from Construction Technology Laboratories, Inc. we could not determine the cause of the lack of set.

Coal Slag

The testing performed as part of this project indicates that the concrete batch made with the coal slag as a fine aggregate had similar 28-day compressive and flexural strength, modulus, and shrinkage characteristics as concrete made with washed concrete sand. The 28-day compressive and flexural strength and modulus results were lower than the approximate expected values for similar concrete made with washed concrete sand (no slag). To more accurately evaluate the test results a reference batch made with washed concrete sand (no slag) should be performed with future trial batches.

The initial setting time was longer than the approximate expected values for similar concrete made with washed concrete sand (no slag). Increased initial setting time can lead to problems during placement of concrete such as increased lateral pressure on forms and delays in finishing operations. Further testing may be warranted to evaluate the feasibility of using an accelerating admixture to decrease the setting time.

The modulus result obtained is lower than the approximate expected values for similar concrete made with washed concrete sand (no slag). The modulus is an expression of a stress and strain relationship. The modulus is very important in design of structural members and further testing and analysis would be required to evaluate the modulus and other stress-strain relationships. For non structural items such as flat work (curbs, gutters, sidewalks, etc.) and gravity applications, where the weight of concrete is needed, such as concrete barriers for vehicles and anchors or dead weights, the modulus is less important.

The shrinkage results obtained are within the approximate expected values for similar concrete made with washed concrete sand (no slag).

The results obtained as part of this testing may be considered an initial indication that it might be feasible to use coal slag in concrete. To more accurately evaluate the effects of coal slag on concrete, a laboratory reference batch not containing slag should be mixed to compare to future trial batches. The effects of coal slag on concrete flexural strength, modulus, and shrinkage for a period greater than 28 days and the effects of coal slag on concrete compressive strength for a period greater than 56 days and effects on other properties of concrete have not been determined and further testing may be warranted.

We suggest further testing to evaluate the long term performance of concrete made with coal slag. One long term property of concrete made with slag that should be further evaluated is expansion. An autoclave expansion test based on a variation of a test such as ASTM C151, Standard Test Method for Autoclave Expansion of portland cement may provide a preliminary indication of possible expansion. It will probably be necessary to blend the coal slag with a natural sand because of the high fines content of the slag. The high fines content can significantly increase the water demand and decrease the strength and durability.

Asphalt Concrete Testing

Two asphalt concrete trial batches were mixed. One batch contained copper slag as a partial replacement of the fine aggregate and one batch contained coal slag as a partial replacement of the fine aggregate. A partial replacement of fine aggregate with slag was used to meet a standard grading. It is expected that if a total replacement of fine aggregate with slag was used the resulting mix would have less desirable placement and compaction characteristics. The mix proportions based on the dry weight of aggregate are as follows:

Coal Slag Batch

Coal Slag- 12%
Rock Dust- 58%
3/8"- 15%
1/2"- 15%

Copper Slag Batch

Copper Slag- 12%
Rock Dust- 54%
3/8"- 10%
1/2"- 24%

Note- Different mix proportions were used for the copper and coal slag batches because the mix proportions are based on a combined gradation of the aggregates. The copper and coal slags had different gradations so the percentage used in the two batches was different.

The asphalt concrete trial batches were batched in general accordance with the asphalt institute MS-2 procedures. The objective of the mix design procedures is to determine the combination of asphalt cement and aggregate that will give desirable performance characteristics. The MS-2 procedures include determining an appropriate blend of aggregates to produce a proper gradation, and selecting the type and amount of asphalt cement to be used as the binder for that gradation. Batches with varying amounts of asphalt cement are batched and specific properties are evaluated. As described in the MS-2 manual, the overall objective for the design of asphalt paving mixes is to determine a

cost effective blend and gradation of aggregates and asphalt that yields a mix having the following properties:

- Sufficient asphalt to ensure a durable pavement.
- Sufficient mix stability to satisfy the demands of traffic without distortion or displacement.
- Sufficient voids in the total compacted mix to allow for a slight amount of additional compaction under traffic loading and a slight amount of asphalt expansion due to temperature increases without flushing, bleeding, and loss of stability.
- A maximum void content to limit the permeability of harmful air and moisture into the mix.
- Sufficient workability to permit efficient placement of the mix without segregation and without sacrificing stability and performance.

The mix design is based on a Standard Specifications for Public Works Construction (SSPWC) type III class C3. The asphalt contents used are in the range specified in the SSPWC and typical of asphalt contents used in the San Diego area. This is the class that fit the gradation using a percentage of the slag. A standard class could not be obtained using more slag.

The proposed mix is run at different asphalt contents and the optimum asphalt content is chosen based on the results of the tests performed. The results for the mixes at different asphalt contents are as follows:

Copper Slag

Asphalt Content, % of Total Mix	4.8	5.3	5.8	6.3
Maximum Theoretical Unit Weight	162.1	160.8	159.5	158.2
Voids in Mineral Aggregate	20.8	21.4	21.3	20.7
Air Voids	11.1	10.6	9.3	7.5
Corrected Marshall Stability	2250	1900	1800	1560
Marshall Flow	15	15	16	17
Bulk Unit Weight	144.0	143.7	144.6	146.3
Compaction Temperature	280	280	280	280

Coal Slag

Asphalt Content, % of Total Mix	4.8	5.3	5.8	6.3
Maximum Theoretical Unit Weight	159.3	158.1	156.9	155.6
Voids in Mineral Aggregate	22.1	22.3	21.2	19.9
Air Voids	10.9	10.0	7.6	4.9
Corrected Marshall Stability	2400	2200	2080	1780
Marshall Flow	13	14	15	16
Bulk Unit Weight	142.0	142.4	145.0	148.0
Compaction Temperature	280	280	280	280

The Voids in Mineral Aggregate (VMA) is the total volume of voids within the mass of the compacted aggregate. If the VMA is too small the mix may have lower durability properties. If the VMA is too large the mix may have lower stability. Typical specifications require a minimum of 15% VMA.

Marshall stability is basically a measure of strength of the asphalt concrete mix. typical specifications require a minimum of 1800 for a heavy traffic load.

Marshall flow is basically a measure of the vertical deformation of the mix under load. Mixes with high flow may experience permanent deformation under traffic loads. Mixes with low flow may be too brittle and crack. Typical specification require flow values between 8 and 16.

Air Voids (voids in total mix) are important for performance and protection from deterioration by air and water. Typical specification require voids between 3 and 5%.

To evaluate the moisture susceptibility of the mixes made with the slag, ASTM D-1075, Standard Test Method for Effect of Water on Cohesion of Compacted Bituminous mixtures was performed. Asphalt concrete can deteriorate due to the influences of moisture. ASTM D-1075 measures the index of retained strength. The typical required minimum index of retained strength is 75%. The results are as follows.

	Index of Retained Strength
Copper Slag Batch	68.6%
Coal Slag Batch	52.6%

> Note- Typical San Diego area aggregates require the addition of an anti stripping additive to meet an index of retained strength of 75%. The copper and coal slag batches that were tested did not contain an anti stripping additive and the results obtained are in the typical expected range for San Diego area aggregates.

Discussion

Copper Slag

The copper slag batch appeared to attain typically specified stability and flow properties between 4.8 and 5.8% asphalt. The air voids at 5.8% asphalt content were not within the typically specified range. The air voids will decrease with increasing asphalt content. At 6.3% asphalt content the air voids were lower although still not in the typically specified range and the stability and flow were no longer in the specified range. Further testing would be warranted to evaluate the use of copper slag in paving asphalt concrete. Copper slag may be more suited for use in asphalt concrete sheet mixes or berm mixes where higher oil contents and lower structural properties may be acceptable.

Coal Slag

The coal slag batch appeared to attain typically specified stability and flow properties between 4.8 and 5.8% asphalt. The air voids at 5.8% asphalt content were not within the typically specified range. The air voids will decrease with increasing asphalt content. At 6.3% asphalt content the air voids were lower but the stability was no longer in the specified range. Further testing would be warranted to evaluate the use of coal slag in paving asphalt concrete. Coal slag may be more suited

for use in asphalt concrete sheet mixes or berm mixes where higher oil contents and lower structural properties may be acceptable.

The asphalt testing performed as part of this project indicate that the asphalt concrete batches made with the coal and copper slags had similar stability and flow as asphalt concrete made with natural rock products. The air voids were higher than the typically expected range. The results should be considered an initial indication that it might be feasible to use coal and copper slag in asphalt concrete. We recommend further testing to evaluate the long term performance of asphalt concrete made with coal and copper slag, particularly since the air voids and VMA are higher than the normal specification limits.

Expansion Index Testing

Expansion Index tests were performed following the Uniform Building Code Standard 29.2. This test is designed to measure the expansive properties of compacted soil. Both the copper and coal slag samples had measured expansion indexes of zero. Table No. 29-C of the Uniform Building Code classifies soil having an expansion indices of zero to 20 as having a very low potential expansion. This test result should only be considered an initial indication that further testing of the slag materials may be warranted. Possible expansion of slag material depends on many factors and may not be indicated by an expansion index test. A comprehensive testing program including autoclave tests would be necessary to further evaluate the use of the slag material as fill.

Please let us know if you have any questions regarding this report.

Sincerely,

LAW/CRANDALL
A Division of Law Engineering and Environmental Services, Inc.

David C. Wilson, RCE 54734
Project Engineer

John R. Theissen, RCE 28313
Principal and Chief Engineer

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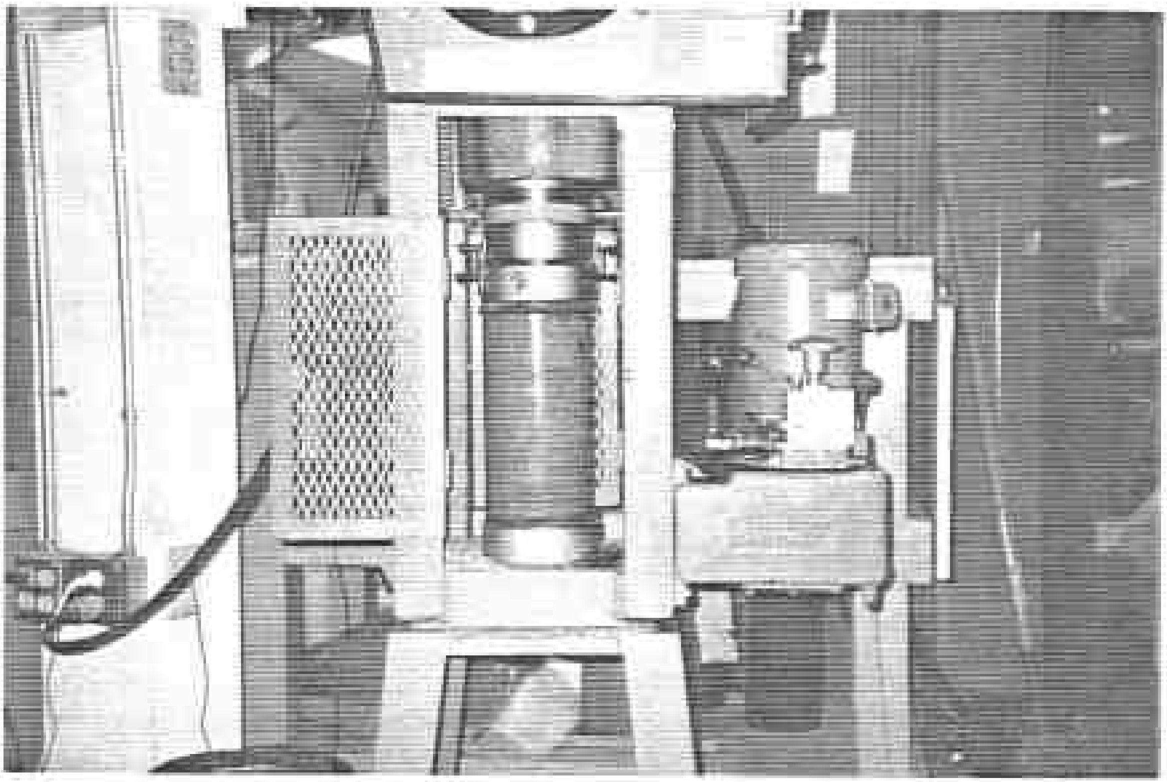

Photo 1: 250,000 lb. compression machine used to test cylinders for compressive strength

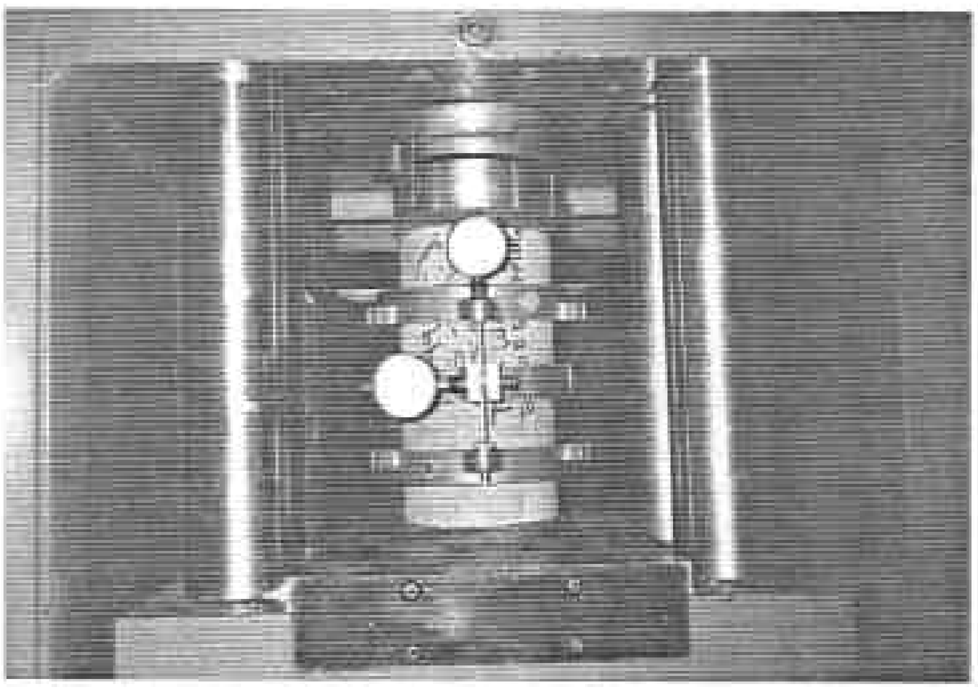

Photo 2: Test cylinder fitted with a compressometer for evaluating deformation and strain characteristics for modulus calculations

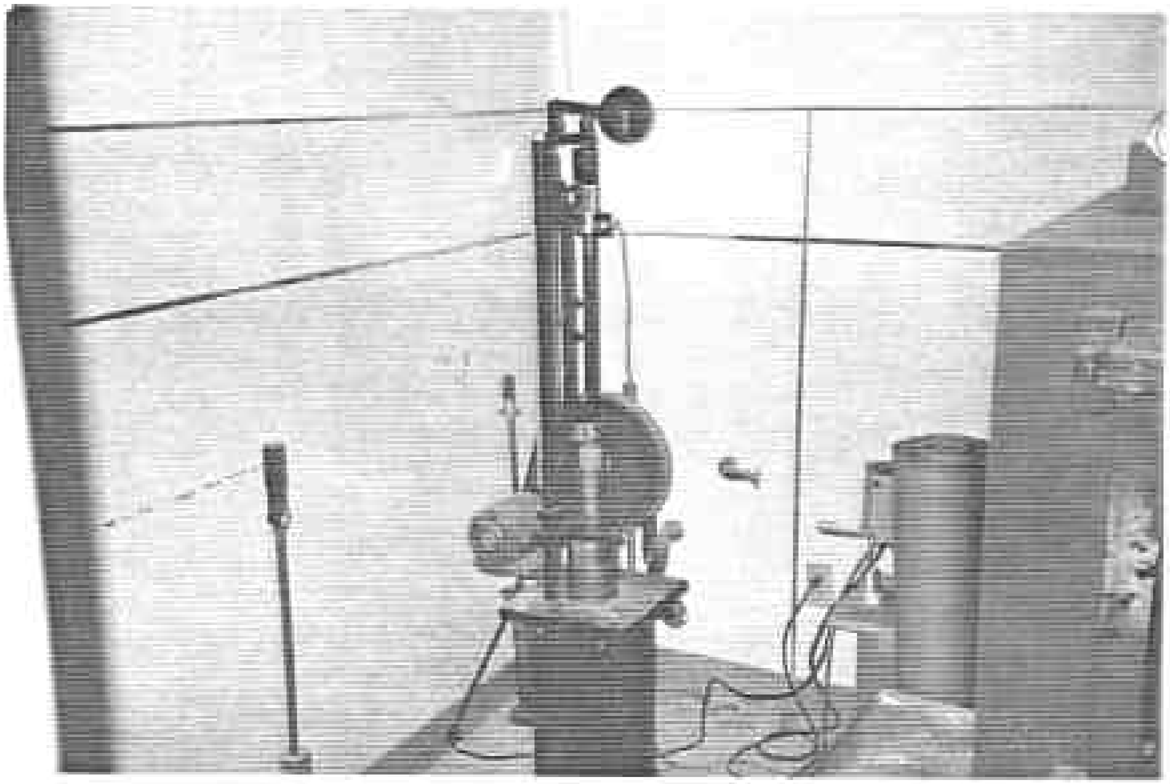

Photo 3: Marshall compaction hammer and mold assembly used for compacting asphalt specimens for the Marshall method (ASTM D1559)

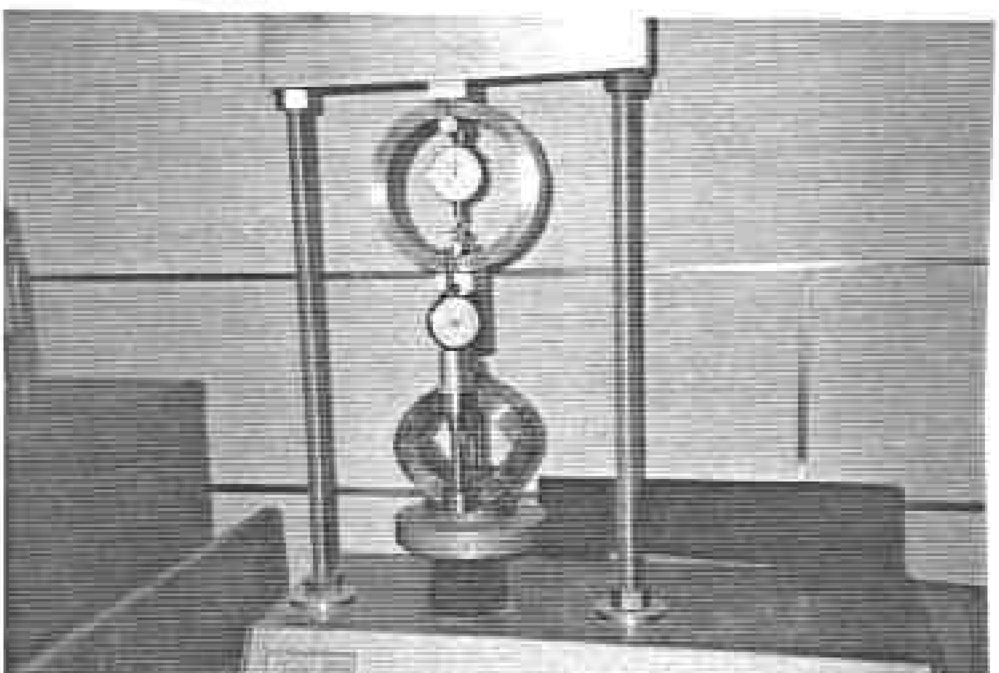

Photo 4: Stability an flow apparatus used for evaluating stability and flow of compacted asphalt specimens.

APPENDIX C

KTA-Tator, Inc.

Report on Reuse Testing

HOUSTON
LOS ANGELES
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KTA-TATOR, INC.
115 Technology Drive, Pittsburgh, PA 15275

PROTECTIVE COATINGS (PAINT) CONSULTANTS: Testing • Instruments • Inspection • Analytical Laboratory

NATIONAL STEEL & SHIPBUILDING COMPANY

USED BLAST ABRASIVE EVALUATION PROGRAM

TEST RESULTS

PURCHASE ORDER MU300063-D

Prepared For

Mr. Barry Graham, MS-22A
National Steel & Shipbuilding Company
Harbor Drive & 28th Street
San Diego, CA 92186-5278

Prepared By
KTA-TATOR, INC.

Michael Reina
csa

Michael P. Reina
September 26, 1996

MPR/MFM:mr
MT00172

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INTRODUCTION

In accordance with the National Steel and Shipbuilding Company (NASSCO) purchase order dated July 27, 1996, number MU300063-D, KTA-Tator, Inc. (KTA) has completed the abrasive testing program. This report contains the results of the abrasive evaluation.

The program encompasses the evaluation of two thermally processed abrasives (coal slag and copper slag) in order to determine if the submitted abrasive media conform with the Steel Structures Painting Council's Abrasive Specification No. 1 (SSPC-AB1). A copy of this specification is attached. Additionally, information concerning the breakdown rate, amount of dust generated, and particle size distribution of the media was determined.

Photographs of the abrasive blasting process, equipment and abrasive media are appended.

SUMMARY

The results of this evaluation are shown in Table 1. Descriptions of test procedures are located in the section of this report entitled “Test Descriptions, Results and Data Interpretation.”

Based on the laboratory results obtained, neither of the abrasive materials submitted by NASSCO met the requirements of the SSPC-AB1 specification. The coals slag abrasive did not meet the requirement for oil content as outlined in section 4.1.6 of the specification, but further testing of separate samples submitted at a later time revealed results within the specification requirement. The copper slag abrasive material did not meet the oil content criteria as received. Additionally, the copper slag media displayed high water soluble contaminants with conductivity levels 3.5 times higher than the maximum allowable as outlined in section 4.1.4 of SSPC-AB 1. Additional samples of the copper slag abrasive received in a separate shipment from NASSCO also did not meet the requirements of SSPC-AB1 for oil content and water soluble contaminants.

NASSCO was interested in learning the effect that washing the abrasive samples in deionized water had on the water soluble contaminant and oil content results. Since ASTM D-4940 “Test Method for Conductimetric Analysis of Water Soluble Ionic Contaminants of Blasting Abrasives” requires the abrasive / deionized water mixture to be filtered and the filtrate tested, NASSCO requested that an additional volume of deionized water be added to the filtered abrasive and re-tested for water soluble contaminants and the presence of oil. This “washing” reduced the water soluble contaminants to levels acceptable by SSPC-AB1 (less than 1000 microsiemens). Additionally, non oil was found in the copper slag abrasive after washing.

Both abrasive materials contained particles of debris ranging in size from approximately ¼ inch to 7/8 inch in diameter. This debris consisted of what appeared to be rust scale, masonry aggregate, pieces of wire and pieces of plastic. This debris could pose a safety hazard to abrasive blast cleaning operators and may damage abrasive blast cleaning equipment. This debris was removed prior to processing, but this debris indicated a potential for contamination of the samples. Both blast cleaning media exhibited high breakdown rates indicating further recycling may not be practical.

Table 1. - Summary Table

Abrasive Samples Tested Initially

Abrasive Media	Average Pre-Blast Particle Size (mm)	Average Post-Blast Particle Size (mm)	Percent Breakdown (%)	Dust Generated (%)	Surface Profile Range (mils)	Average Surface Profile (mils)
Coal Slag	0.53	0.25	52.8	12.2	3.9 to 4.0	3.98
Copper Slag	0.47	0.27	42.5	9.0	3.5 to 4.0	3.72

Abrasive Media	Specific Gravity Obtained	Minimum Specific Gravity Required by SSPC-AB 1	Hardness Obtained (Mohs)	Minimum Hardness Required by SSPC-AB 1 (Mohs)	Water Soluble Contaminants Obtained (microsiemens)	Maximum Water Soluble Contaminants Allowed by SSPC-AB 1 (microsiemens)	Oil Content Obtained	Maximum Oil Content Allowed by SSPC-AB 1
Coal Slag	2.89	2.5	> 6	6	235	1000	Oil Present	None
Copper Slag	2.74	2.5	> 6	6	3500	1000	Oil Present	None

Additional Abrasive Samples

Abrasive Media	Water Soluble Contaminants Obtained (microsiemens)	Oil Content Obtained
Coal Slag	220	None
Copper Slag	4200	Oil Present

Washed Abrasive Samples

Abrasive Media	Water Soluble Contaminants Obtained (microsiemens)	Oil Content Obtained
Coal Slag	120	None
Copper Slag	640	None

TEST DESCRIPTIONS, RESULTS AND DATA INTERPRETATION

A description of the test protocol for each of the evaluations conducted follows, along with a summarization and interpretation of test results.

Abrasive Sampling Procedure

The entire amount of each abrasive media was riffled separately three times to insure homogeneity and provide a uniform distribution of particle sizes. The riffling device was cleaned before and after use with clean, dry compressed air to eliminate any cross contamination between the coal slag and copper slag materials. Abrasive samples were collected from the homogenous mixture for all testing. This procedure meets in general the requirements of ASTM D-75 “Method for Sampling Aggregates.”

Pre-Blast Size Distribution

Sieve analysis was performed for the test abrasive to establish the pre-blast particle size distribution for each of the two abrasives. The information was subsequently used to calculate breakdown characteristics of the abrasive materials. Testing was performed in general accordance with ASTM C-136 “Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.” Briefly, the entire amount of each abrasive was riffled three times to obtain a uniform mixture of particle sizes. Subsequently, a one-hundred (100) gram sample of each abrasive was tamped through a series of thirteen sieves for seven (7) minutes. The USA Standard sieve sizes used for the testing included No.’s 10, 12, 16, 20, 30, 40, 50, 60 70, 100, 140, 200, 270 and a solid pan at the base of the sieves. The abrasive retained on each sieve was weighed on a balance capable of measuring to 0.1 gram. The percent abrasive retained on each sieve was recorded. Data are found in Appendix 1.

Test Results

The results of the pre-blast particle size distribution for both the coal slag abrasive and the copper slag abrasive are found in Appendix 1. The post-blast analyses (for calculating breakdown characteristics) are also found in Appendix 1.

Percentage Breakdown / Dust Generation

Percentage breakdown /dust generation testing was performed to determine post-blast cleaning particle size distribution and the quantity of dust generated by the test abrasives. Abrasive breakdown was calculated based on the comparison of the pre-blast versus the post-blast particle size distribution of the abrasive mixture. Percentage breakdown was determined by finding the percent change in average particle size of each abrasive. A specially designed blast chamber equipped with an impact plate and a dust reclamation bag was used for the testing. Figure 1. is a drawing of the blast reclamation chamber. Using a ½ inch diameter abrasive metering orifice (located at the base of the blast pot) and a 3/8 inch venturi blast nozzle, a 100 pound quantity of each abrasive was propelled into the chamber at an air pressure of 100 psi against a 3/16 inch steel plate at a distance of 18 inches from the nozzle to the steel plate. The dust accumulated in the reclamation bag was weighed to determine the amount of dust generated (percentage of total sample weight). The dust was then combined with the settled abrasive, and the resulting mixture was riffled two times to obtain a uniform mixture of particle sizes. A sieve analysis was performed on the riffled abrasive to determine the post-blast cleaning particle size distribution and resulting percentage breakdown (see method described in the “pre-blast particle size distribution”).

Test Results

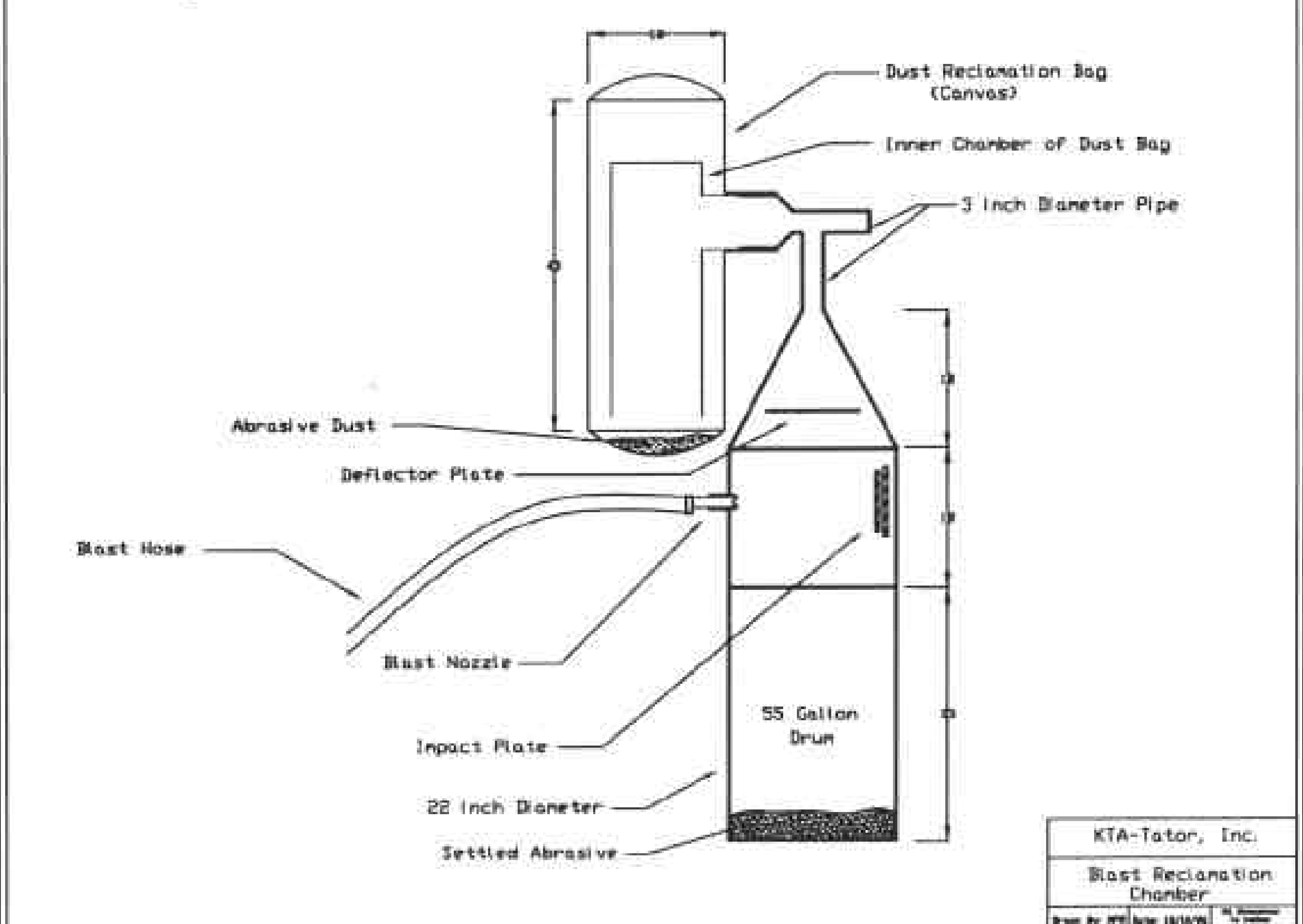
The percentage breakdown for the coal slag abrasive was determined to be 52.8%. The copper slag abrasive material revealed a percentage breakdown of 42.6%. The amount of dust generated by the coal slag abrasive was 12.2%. The amount of dust generated by the copper slag abrasive was 9.0%

Data Interpretation

Abrasive breakdown data is useful in assessing the recyclability of an abrasive. It refers to the percentage of the original particle size distribution that “shifted out” (decreased) as a result of surface impingement during abrasive blast cleaning. The test results yielded the following conclusions:

Both the coal slag and the copper slag abrasives tested possessed a high percentage particle breakdown compared to abrasive materials that are typically recycled (steel shot, steel grit, aluminum oxide, garnet); consequently, they are not deemed good candidates for further recycling unless provisions are made to remove the fine particle sizes (greater than 70 mesh). Typical values of percentage breakdown for steel grit and steel shot abrasives range from less than 1% to 3%. Typical percentage breakdown values range from 10% to 20% for aluminum oxide abrasives, and 15% to 30% for garnet abrasives.

Figure 1. KTA-TATOR ABRASIVE BREAKDOWN CHAMBER



Surface Profile Generation

Surface profile generation testing was performed in accordance with section 4.3 of SSPC-AB 1. Abrasive blast cleaning with both the coal slag and the copper slag was performed with a 3/8 inch (No. 6) venturi nozzle with a nozzle pressure of 100 psi at a distance of 18 inches from the steel surface at an angle of 90 degrees. Five surface profile measurements were taken, at randomly selected locations on the test panels, in accordance with Method C of ASTM D-4417 "Test Method for Field Measurement of Surface Profile of Blast Cleaned Steel".

Test Results

The surface profile generation results are shown in the following table:

Abrasive	Surface Profile (mils)					Average Surface Profile (mils)
Coal Slag	4.0	4.0	4.0	3.9	4.0	3.98
Copper Slag	3.5	3.9	3.6	3.6	4.0	3.72

Data Interpretation

Both the coal slag and the copper slag abrasive met the requirements of SSPC-AB 1 and both would be deemed Type II - Slag Abrasives, Grade 4 by the specification.

Abrasive Specific Gravity

The specific gravity of each abrasive was determined in accordance with ASTM C-128 "Test Method for Specific Gravity and Absorption of Fine Aggregates" as outlined by SSPC-AB 1 section 4.1.1.

Test Results

The results of this testing are shown the table that follows. Also shown is the calculated approximate bulk density of the materials. This was determined by multiplying the specific gravity by the density of water (62.4 lb/ft^3).

Abrasive	Specific Gravity	Bulk Density (lb./ft^3)
Coal Slag	2.89	180
Copper Slag	2.74	171

Data Interpretation

The minimum specific gravity required by SSPC-AB 1 is 2.5, therefore both abrasive media met this requirement. Generally, copper slag abrasives have higher specific gravity values than coal slag abrasives. The results obtained for this project were determined from only one randomly selected sample of each abrasive. Averaging the results of multiple testing may provide more significant results. Abrasive having higher densities tend to develop higher impact energy under the same operating conditions, which in turn increase the effectiveness of the abrasive.

Abrasive Hardness

Hardness of each abrasive was determined in accordance with section 4.1.2 of SSPC-AB 1.

Test Results

The coal slag abrasive and the copper slag abrasive exhibited hardness values greater than 6 on the Mohs scale.

Data Interpretation

The hardness of both abrasive media exceeded the minimum requirement dictated by the specification.

Water Soluble Contaminants

The conductivity of the abrasive was determined in accordance with ASTM D-4940 "Test Method for Conductimetric Analysis of Water Soluble Ionic Contaminants of Blasting Abrasives". Briefly, this method involved mixing a known amount of abrasive with a known amount of water, mixing for a stated period of time, filtering, and then analyzing the solution with a conductivity meter.

Test Results

The results are shown in the following table:

Abrasive	Conductivity (microsiemens)
Coal Slag	235
Copper Slag	3500

Data Intepretation

SSPC-AB 1 requires that the conductivitiy of mineral and slag abrasives be less than 1000 microsiemens. The copper slag material did not meet this requirement and subsequently does not meet the requirements of SSPC-AB 1 specification. KTA did not test samples of the abrasive media prior to thermal processing, therefore no information exists concerning the water soluble contaminants of the virgin material. Industrial methods may be available to reduce the amount of water soluble contaminants.

<u>Oil Content</u>

The oil content of the abrasive was determined in accordance with SSPC-AB 1. Briefly, this method involved mixing abrasive with an equal volume of deionized water, letting it stand for 30 minutes, and then evaluating the water for the presence of oil.

Test Results

The coal slag abrasive and the copper slag abrasive revealed the presence of oil.

Data Interpretation

No amount of oil is permitted by the SSPC-AB 1 specification. Therefore the two abrasives samples submitted to KTA did not meet the specification requirements as received. Since the SSPC-AB 1 specification does not require that the type, quantity, color, or physical characteristics of the oil be identified, this information was not determined.

<u>Water Soluble Contaminants / Oil Content of Additional Abrasive Samples</u>

Additional samples of both the thermally recycled coal slag and copper slag media were tested to verify the water soluble contaminant and oil content results. These tests were preformed as described previously. The conductivity of the coal slag abrasive was determined to be 220 microsiemens. The conductivity of the copper slag abrasive was determined to be 4200 microsiemens. No oil was observed in the coal slag media. The copper slag abrasive contained a trace amount of oil in a thin film floating just beneath the surface of the water. The oil was a reddish-brown reflective color and had an approximate circular size of 1/8 inch diameter.

Water Soluble Contaminants / Oil Content of Washed Abrasives

Since ASTM D-4940 "Test Method for Conductimetric Analysis of Water Soluble Ionic Contaminants of Blasting Abrasives" requires the abrasive / deionized water mixture to be filtered and the filtrate tested, NASSCO requested that an additional volume of deionized water be added to the filtered abrasive and re-tested for water soluble contaminants and the presence of oil. This was done to determine what effect washing the abrasives with deionized water has on the results. Test results obtained after this "washing" were:

A 45% decrease in conductivity for the coal slag abrasive
(220 microsiemens to 120 microsiemens)

An 80% decrease in conductivity for the copper slag abrasive
(4200 microsiemens to 840 microsiemens)

No oil was observed in either the coal slag or the copper slag media.

KTA Sieve Analysis Report Form	MATF 100R.2
Revision No. 2	Issued 3/12/96

KTA-Tator, Inc.

MATS Group

Sieve Analysis

Sample Number: MATS 1405

Weight of Sample: 100 grams

Sample Description: Coal Slag Abrasive
Pre-Blast Abrasive

Date: 9/3/96

Technician: Stanford Galloway

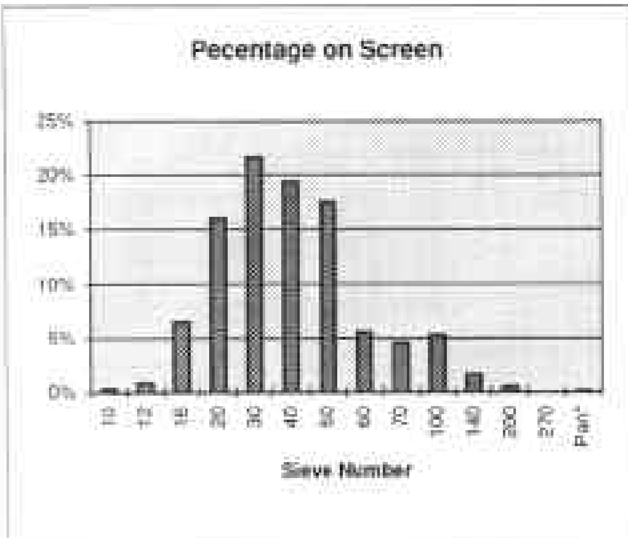
Job: MT00172 NASSCO

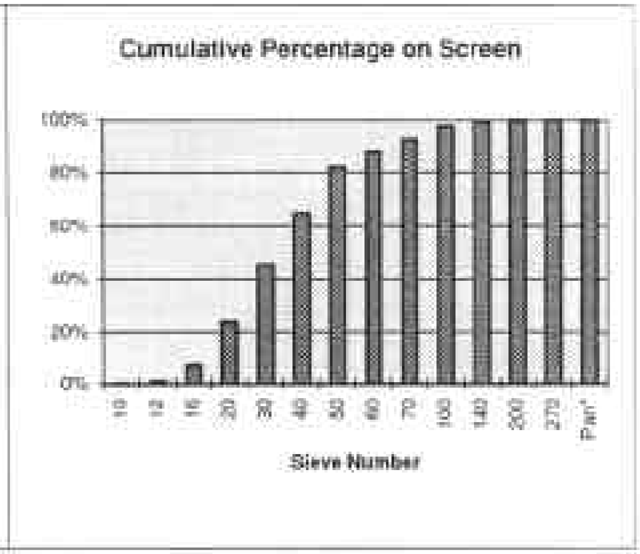
Sieve #	Cup and Grit	Cup	Grit	% of Total	Cum % of Total	S.O.S.** in mm	Particle Size Avg
10	12.9	12.6	0.3	0.30%	0.30%	2.000	0.60
12	13.7	12.9	0.8	0.80%	1.10%	1.700	1.36
16	20.0	13.5	6.5	6.50%	7.60%	1.180	7.67
20	28.8	12.7	16.1	16.10%	23.70%	0.850	13.69
30	34.5	12.8	21.7	21.70%	45.40%	0.600	13.02
40	32.1	12.7	19.4	19.40%	64.80%	0.425	8.25
50	30.4	12.9	17.5	17.50%	82.30%	0.300	5.25
60	18.4	12.8	5.6	5.60%	87.90%	0.250	1.40
70	17.5	12.9	4.6	4.60%	92.50%	0.210	0.97
100	18.2	12.9	5.3	5.30%	97.80%	0.150	0.80
140	14.5	12.9	1.6	1.60%	99.40%	0.110	0.18
200	12.9	12.4	0.5	0.50%	99.90%	0.075	0.04
270	12.7	12.7	0	0.00%	99.90%	0.053	0.00
Pan*	12.9	12.8	0.1	0.10%	100.00%	0.038	0.00
Total			100	100.00%		Sum =	53.21

* Approximated as a #400 Sieve

** S.O.S. is Screen Opening Size

Average particle size = Sum / Total Wt. (in mm) = 0.53





KTA Sieve Analysis Report Form	MATF 100R.2
Revision No. 2	Issued 3/12/96

KTA-Tator, Inc.

MATS Group

Sieve Analysis

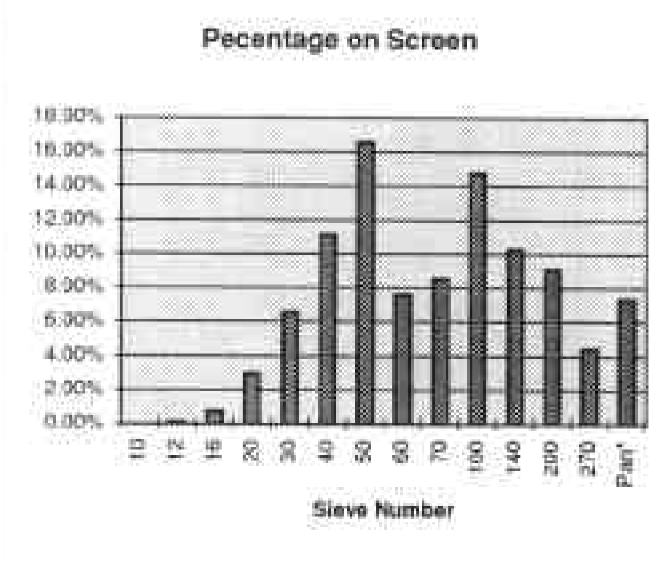
Sample Number: MATS 1407
Weight of Sample: 100 grams
Sample Description: Coal Slag Abrasive
Post-Blast Abrasive

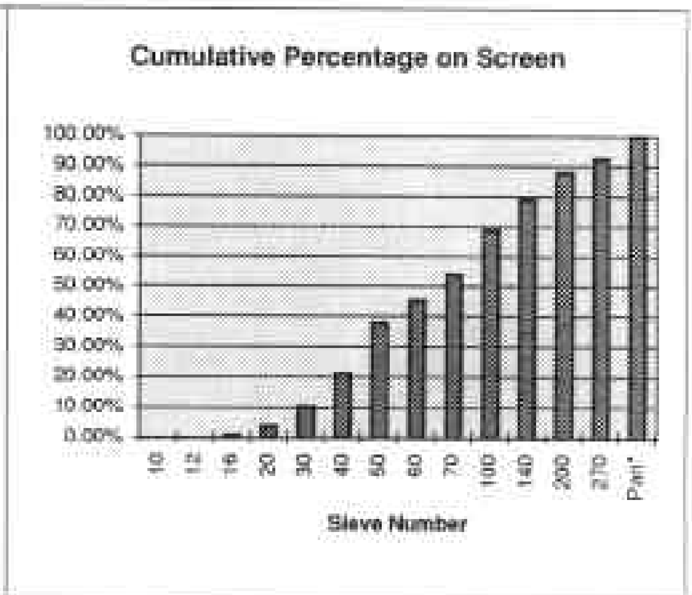
Date: 9/4/96
Technician: Stanford Galloway
Job: MT00172 NASSCO

Sieve #	Cup and Grit	Cup	Grit	% of Total	Cum % of Total	S.O.S.** in mm	Particle Size Avg
10	12.6	12.6	0	0.00%	0.00%	2.000	0.00
12	13.0	12.9	0.1	0.10%	0.10%	1.700	0.17
16	14.2	13.5	0.7	0.70%	0.80%	1.180	0.83
20	15.6	12.7	2.9	2.91%	3.72%	0.850	2.47
30	19.3	12.8	6.5	6.53%	10.25%	0.600	3.90
40	23.8	12.7	11.1	11.16%	21.41%	0.425	4.72
50	29.4	12.9	16.5	16.58%	37.99%	0.300	4.95
60	20.4	12.8	7.6	7.64%	45.63%	0.250	1.90
70	21.4	12.9	8.5	8.54%	54.17%	0.210	1.79
100	27.6	12.9	14.7	14.77%	68.94%	0.150	2.21
140	23.1	12.9	10.2	10.25%	79.20%	0.110	1.12
200	21.4	12.4	9	9.05%	88.24%	0.075	0.68
270	17.1	12.7	4.4	4.42%	92.66%	0.053	0.23
Pan*	20.1	12.8	7.3	7.34%	100.00%	0.038	0.28
Total			99.5	100.00%		Sum =	25.23

* Approximated as a #400 Sieve
** S.O.S. is Screen Opening Size

Average particle size = Sum / Total Wt. (in mm) = 0.25





KTA Sieve Analysis Report Form	MATF 100R.2
Revision No. 2	Issued 3/12/96

KTA-Tator, Inc.

MATS Group

Sieve Analysis

Sample Number MATS 1406 100 Mesh Reclaimed Slag Date 9/3/96

Weight of Sample 100 grams Technician Stanford Galloway

Sample Description 100 Mesh Copper Slag Abrasive Job MT00172 NASSCO

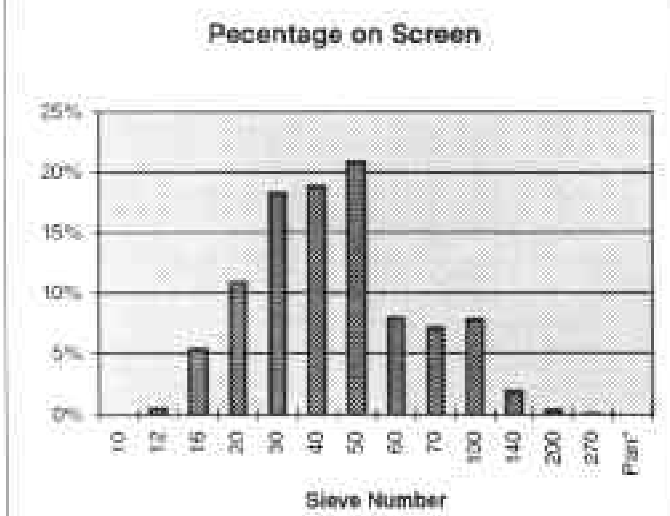
Pre-Blast Abrasive

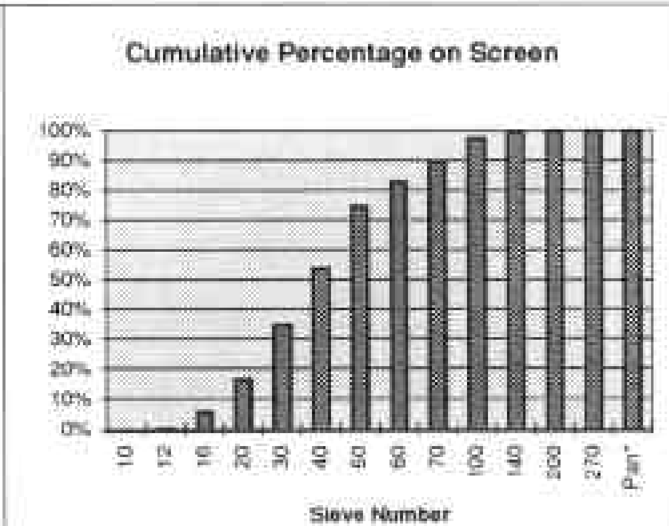
Sieve #	Cup and Grit	Cup	Grit	% of Total	Cum % of Total	S.O.S.** in mm	Particle Size Avg
10	12.6	12.6	0	0.00%	0.00%	2.000	0.00
12	13.4	12.9	0.5	0.50%	0.50%	1.700	0.85
16	18.8	13.5	5.3	5.31%	5.81%	1.180	6.25
20	23.6	12.7	10.9	10.91%	16.72%	0.850	9.27
30	31.1	12.8	18.3	18.32%	35.04%	0.600	10.98
40	31.6	12.7	18.9	18.92%	53.95%	0.425	8.03
50	33.7	12.9	20.8	20.82%	74.77%	0.300	6.24
60	20.7	12.8	7.9	7.91%	82.68%	0.250	1.98
70	20.0	12.9	7.1	7.11%	89.79%	0.210	1.49
100	20.7	12.9	7.8	7.81%	97.60%	0.150	1.17
140	14.8	12.9	1.9	1.90%	99.50%	0.110	0.21
200	12.8	12.4	0.4	0.40%	99.90%	0.075	0.03
270	12.8	12.7	0.1	0.10%	100.00%	0.053	0.01
Pan*	12.8	12.8	0	0.00%	100.00%	0.038	0.00
Total			99.9	100.00%		Sum =	46.50

* Approximated as a #400 Sieve

** S.O.S. is Screen Opening Size

Average particle size = Sum / Total Wt. (in mm) = 0.47





KTA Sieve Analysis Report Form	MATF 100R.2
Revision No. 2	Issued 3/12/96

KTA-Tator, Inc.

MATS Group

Sieve Analysis

Sample Number MATS 1408 100 Mesh Reclaimed Slag

Weight of Sample 100 grams

Sample Description 100 Mesh Copper Slag Abrasive Post-Blast Abrasive

Date 9/5/96

Technician Stanford Galloway

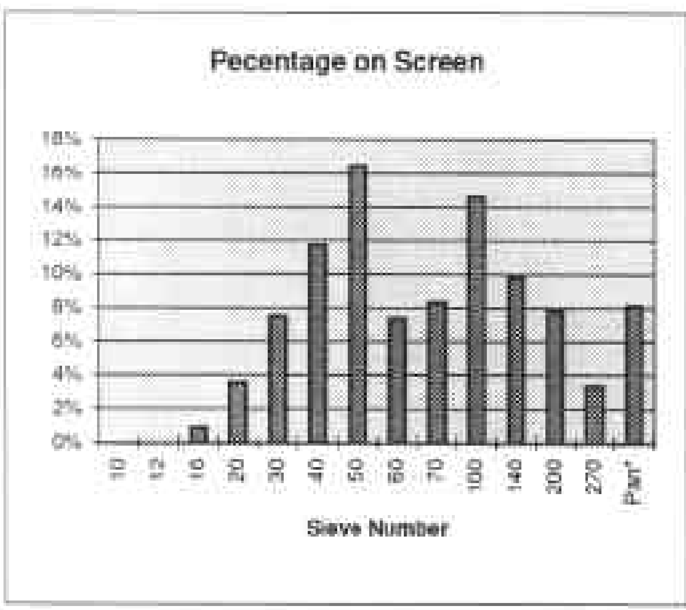
Job MT00172 NASSCO

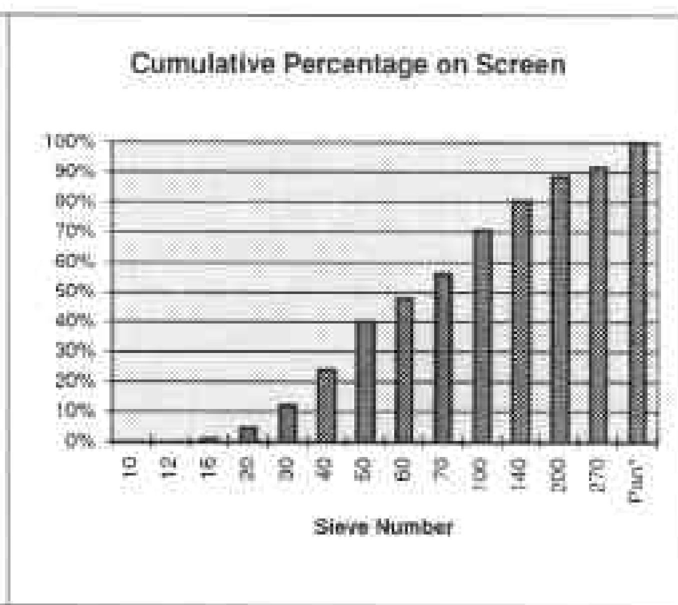
Sieve #	Cup and Grit	Cup	Grit	% of Total	Cum % of Total	S.O.S.** in mm	Particle Size Avg
10	12.6	12.6	0	0.00%	0.00%	2.000	0.00
12	12.9	12.9	0	0.00%	0.00%	1.700	0.00
16	14.4	13.5	0.9	0.90%	0.90%	1.180	1.06
20	16.3	12.7	3.6	3.61%	4.52%	0.850	3.06
30	20.3	12.8	7.5	7.53%	12.05%	0.600	4.50
40	24.4	12.7	11.7	11.75%	23.80%	0.425	4.97
50	29.3	12.9	16.4	16.47%	40.26%	0.300	4.92
60	20.2	12.8	7.4	7.43%	47.69%	0.250	1.85
70	21.2	12.9	8.3	8.33%	56.02%	0.210	1.74
100	27.5	12.9	14.6	14.66%	70.68%	0.150	2.19
140	22.7	12.9	9.8	9.84%	80.52%	0.110	1.08
200	20.3	12.4	7.9	7.93%	88.45%	0.075	0.59
270	16.1	12.7	3.4	3.41%	91.87%	0.053	0.18
Pan*	20.9	12.8	8.1	8.13%	100.00%	0.038	0.31
Total			99.6	100.00%		Sum =	26.46

* Approximated as a #400 Sieve

** S.O.S. is Screen Opening Size

Average particle size = Sum / Total Wt. (in mm) = 0.27





Pre and Post Blast Cleaning Analysis

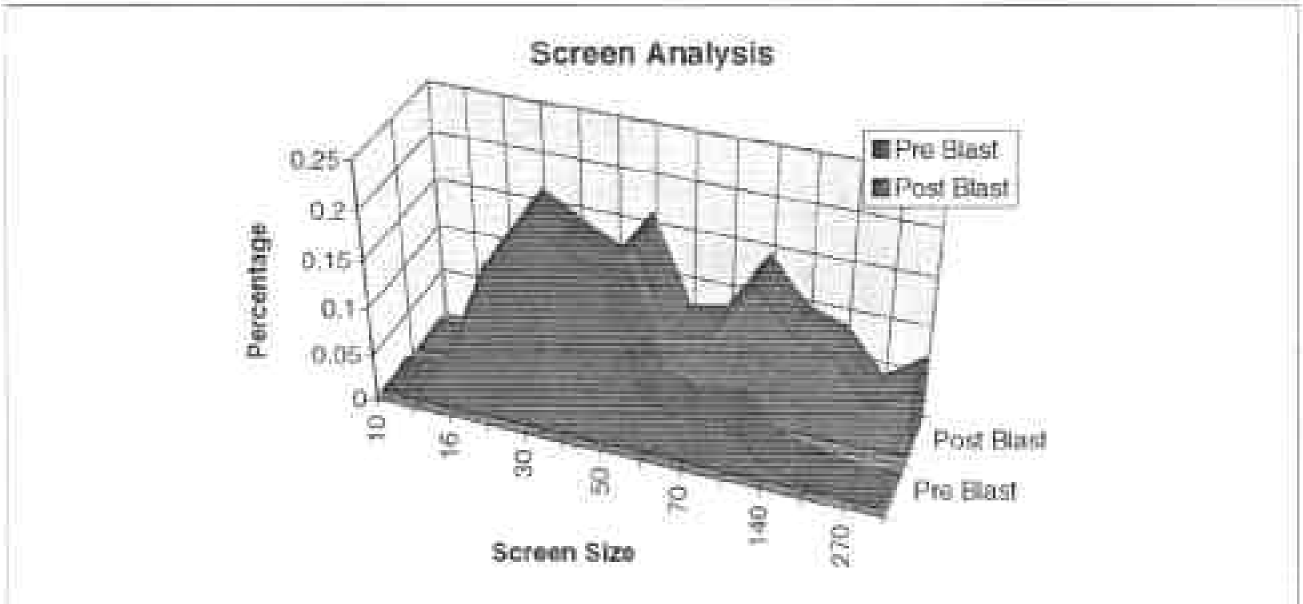
Coal Slag

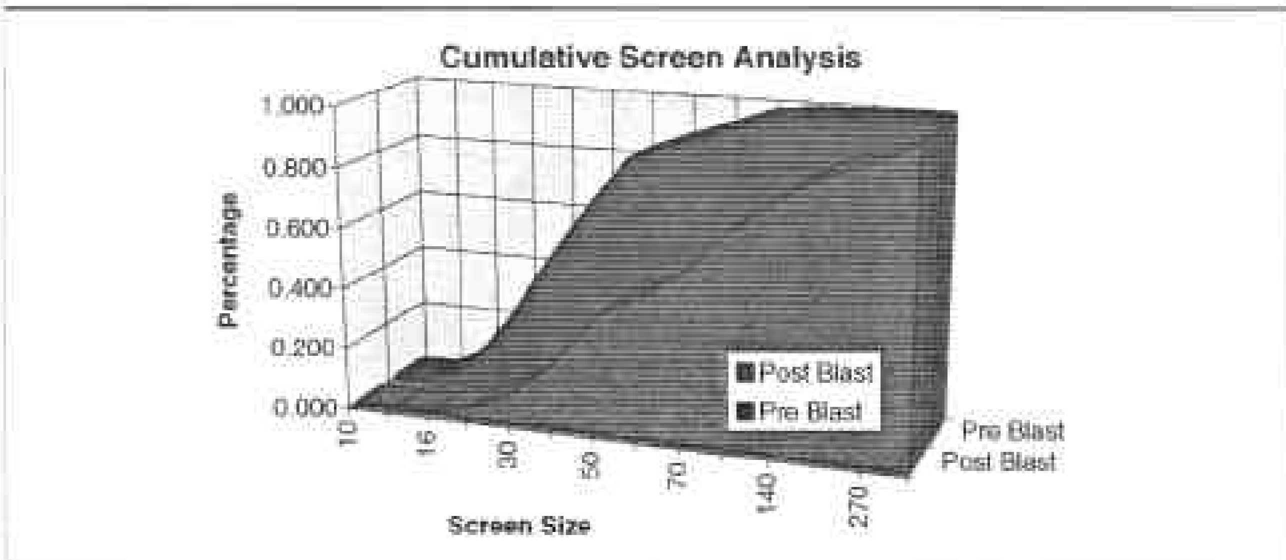
100 psi, # 6 Nozzle (.375"), 1/2" diameter metering valve

Screen	Pre Blast	Post Blast
10	0.003	0.000
12	0.008	0.001
16	0.065	0.007
20	0.161	0.029
30	0.217	0.065
40	0.194	0.112
50	0.175	0.166
60	0.056	0.076
70	0.046	0.085
100	0.053	0.148
140	0.016	0.103
200	0.005	0.090
270	0.000	0.044
Pan	0.001	0.073

Cumulative

Screen	Post Blast	Pre Blast
10	0.000	0.003
12	0.001	0.011
16	0.008	0.076
20	0.037	0.237
30	0.102	0.454
40	0.214	0.648
50	0.380	0.823
60	0.456	0.879
70	0.541	0.925
100	0.689	0.978
140	0.792	0.994
200	0.882	0.999
270	0.926	0.999
Pan	0.999	1.000





Pre and Post Blast Cleaning Analysis

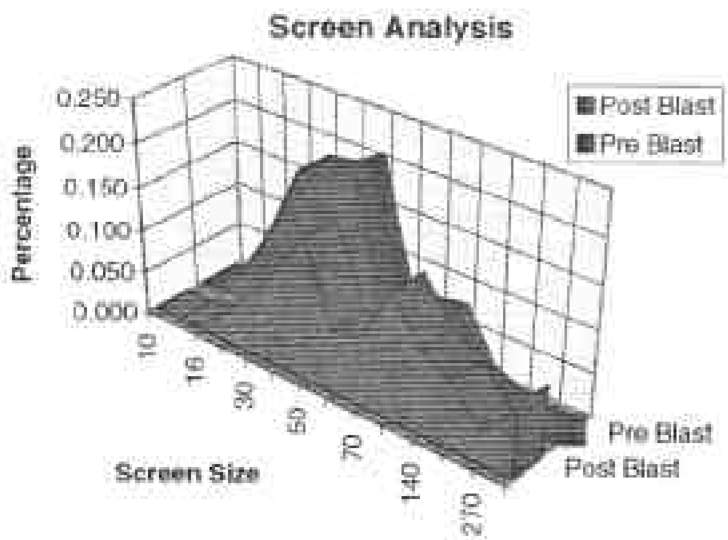
Copper Slag

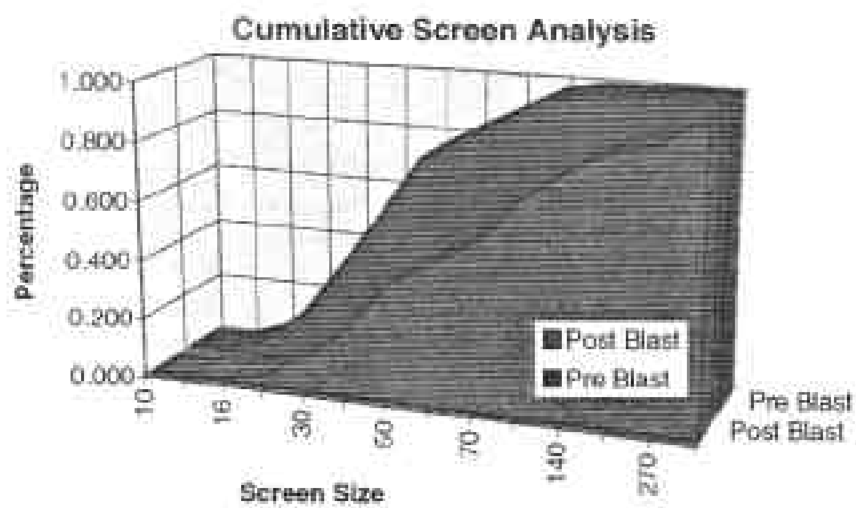
100 psi, # 6 Nozzle (.375"), 1/2" diameter metering valve

Screen	Post Blast	Pre Blast
10	0.000	0.000
12	0.000	0.005
16	0.009	0.053
20	0.036	0.109
30	0.075	0.183
40	0.117	0.189
50	0.164	0.208
60	0.074	0.079
70	0.083	0.071
100	0.146	0.078
140	0.098	0.019
200	0.079	0.004
270	0.034	0.001
Pan	0.081	0.000

Cumulative

Screen	Post Blast	Pre Blast
10	0.000	0.000
12	0.000	0.005
16	0.009	0.058
20	0.045	0.167
30	0.120	0.350
40	0.237	0.539
50	0.401	0.747
60	0.475	0.826
70	0.558	0.897
100	0.704	0.975
140	0.802	0.994
200	0.881	0.998
270	0.915	0.999
Pan	0.996	0.999





Steel Structures Painting Council
ABRASIVE SPECIFICATION NO. 1
Mineral and Slag Abrasives

1. Scope

1.1 This specification defines the requirements for selecting and evaluating mineral and slag abrasives used for blast cleaning steel and other surfaces for painting and other purposes.

1.2 The abrasives covered by this specification are primarily intended for one-time use without recycling; reclaimed materials must again be tested against and meet the requirements of this specification. (See Note 7.1.)

2. Description

2.1 The abrasives are categorized into two types, three classes and five grades as described below. Normally the user shall specify the types, classes and grades required. If no abrasive type is specified, then either Type I or Type II is considered acceptable. If no abrasive class is specified, then any class will be considered acceptable. If no abrasive profile grade is specified, the abrasive shall satisfy the requirements of any of the five grades listed.

2.2 The following abrasive types are included.

Type I - Natural Mineral Abrasives.

These are naturally occurring minerals, including, but not limited to, quartz sands, flint, garnet, staurolite, and olivine.

Type II - Slag Abrasives.

These are slag by-products of coal-fired power production or of metal (such as copper or nickel) smelting.

2.3 The following abrasive classes are included.

Class A - Crystalline silica less than or equal to 1.0%

Class B - Crystalline silica less than or equal to 5.0%

Class C - Unrestricted crystalline silica

The definition and requirements for Classes A, B and C are given in Section 4.2.

2.4 The abrasive grades and associated profile ranges are listed below.

Grade 1 - Abrasives which produce surface profiles of 0.5 to 1.5 mils (13 to 38 microns) when tested in accordance with Section 4.3.

Grade 2 - Abrasives which produce surface profiles of 1.0 to 2.5 mils (25 to 64 microns) when tested in accordance with Section 4.3.

Grade 3 - Abrasives which produce surface profiles of 2.0 to 3.5 mils (51 to 89 microns) when tested in accordance with Section 4.3.

Grade 4 - Abrasives which produce surface profiles of 3.0 to 5.0 mils (75 to 127 microns) when tested in accordance with Section 4.3.

Grade 5 - Abrasives which produce surface profiles of 4.0 to 6.0 mils (102 to 152 microns) when tested in accordance with Section 4.3.

Other profile ranges may be designated by the purchaser.

3. Reference Standards

3.1 The reference standards listed in Sections 3.4 and 3.5 form a part of this specification.

3.2 The latest issue, revision, or amendment of the referenced standards in effect on the date of invitation to bid shall govern unless otherwise stated.

3.3 If there is a conflict between the requirements of any of the cited reference standards and this specification, the requirements of this specification shall prevail.

3.4 STEEL STRUCTURES PAINTING COUNCIL (SSPC) SPECIFICATIONS:

Vis 1	Visual Standard for Abrasive Blast Cleaned Steel
SP 10	Near-White Blast Cleaning

3.5 AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM) STANDARDS:

C-128	Test Method for Specific Gravity and Absorption of Fine Aggregates
C-136	Test Method for Sieve Analysis of Fine and Coarse Aggregates
C-566	Test Method for Total Moisture Content of Aggregate by Drying
C-702	Method for Reducing Field Samples of Aggregate to Testing Size
D-75	Method for Sampling Aggregates
D-1125	Test Methods for Electrical Conductivity and Resistivity of Water
D-4417	Test Method for Field Measurement of Surface Profile of Blast Cleaned Steel

D-4940 Test Method for Conductimetric Analysis of Water Soluble Ionic Contaminants of Blasting Abrasives

E-1132 Practice for Health Requirements Relating to Occupational Exposure to Quartz Dust

4. Requirements

4.1 GENERAL PHYSICAL AND CHEMICAL PROPERTIES

The abrasive shall meet all the requirements of paragraphs 4.1.1 through 4.1.6. These are summarized in Table 1.

4.1.1 Specific Gravity

The specific gravity shall be a minimum of 2.5 as determined by ASTM C-128.

4.1.2 Hardness

The hardness shall be a minimum of 6 on the Mohs scale when tested as follows: Examine the material under low-power microscope (10X) and if grains of different colors or character are present, select a few grains of each. Place in succession the grains thus differentiated between two glass microscope slides. While applying pressure, slowly move one slide over the other with a reciprocating motion for 10 seconds. Examine the glass surface, and if scratched, the material shall be considered as having a minimum hardness of 6 on the Mohs scale. If more than 25% of the grains by count fail to scratch the glass surface, the abrasive does not meet this specification.

4.1.3 Weight Change on Ignition

The maximum permissible loss on ignition is 1.0% and the maximum permissible gain is 5.0% when tested as follows: A representative portion of the sample shall be ground in an agate mortar and thoroughly dried at 220-230 °F (105-110 °C) for one hour. Transfer approximately 1 gram of the dried sample to a fired crucible with cover and weigh to the nearest milligram. ...iously heat the crucible with contents, at first partially covered, and then at approximately 1382 ± 90 °F (750 ± 50 °C) ...ered. Hold at 1382 °F (750 °C) for 30 minutes, then cool in a desiccator and reweigh. The percent of weight change shall be computed as follows:

$$\%\ \text{weight change} = \frac{(\text{final wt.} - \text{orig. wt.}) \times 100}{\text{orig. wt.}}$$

4.1.4 Water Soluble Contaminants

The conductivity of the abrasive shall not exceed 1000 microsiemen when tested in accordance with ASTM D-4940. (See Note 7.3.)

4.1.5 Moisture Content

The maximum moisture content shall be 0.5% by weight, when tested in accordance with ASTM C-566.

4.1.6 Oil Content

The sample, in water, when tested in 4.1.4, shall show no presence of oil, either on the surface of the water or as an emulsion in the water, when examined visually after standing for 30 minutes.

4.2 CRYSTALLINE SILICA CONTENT

All abrasives must be classed based on crystalline silica content (see Note 7.4). Abrasives designated as Class A or B must meet the requirements of paragraphs 4.2.1 or 4.2.2 respectively.

4.2.1 Class A - Less Than 1% Crystalline Silica

Abrasives shall contain no more than 1.0% by weight of crystalline silica when determined in accordance with procedures described in 4.2.4.

4.2.2 Class B - Less than 5% Crystalline Silica

Abrasives shall contain no more than 5.0% by weight of crystalline silica when determined in accordance with procedures described in 4.2.4.

4.2.3 Class C - Unrestricted Crystalline Silica

No restrictions on crystalline silica content.

4.2.4 Crystalline Silica

The crystalline silica content shall be determined by the use of infrared spectroscopy or by other analytical procedures, such as wet chemical or X-ray diffraction analyses.

4.3 SURFACE PROFILE

The average surface profile, when determined in accordance with the description below, shall be within the ranges

TABLE 1
REQUIREMENTS FOR CHEMICAL AND PHYSICAL PROPERTIES OF ABRASIVES

...ion	Properties	Test Procedure	Requirements Min.	Requirements Max.
...	specific gravity	ASTM C-128	2.5	—
...2	hardness	Mohs scale	6	—
	weight change on ignition	Heat to 1382 °F (750 °C)	− 1.0% (loss)	+ 5.0% (gain)
...4	water soluble contaminant	ASTM D-4940	—	1000 microsiemens
	moisture content	ASTM C-566	—	0.5%
...	oil content	observe surface of water extract	—	none

specified in Section 2.4. A representative sample of the material shall be obtained in accordance with ASTM D-75 and used to abrasive blast a 2-foot by 2-foot by 1/4 inch (61 cm x 61 cm x 6 mm) mild steel plate of SSPC-Vis 1 Rust Grade A to a cleanliness of SSPC-SP 10 (Near-White Blast Cleaning). The blasting shall be done using a 3/8 in (9.5 mm) #6 venturi nozzle with a nozzle pressure of 95 ± 5 psig (670 ± 35 kilopascals) at a distance of 24 ± 6 inches (61 ± 15 cm) from the surface at an angle of 75 to 105 degrees. The resultant surface profile shall be measured at a minimum of 5 locations in accordance with Method C of ASTM D-4417 (see Note 7.5). The average measured profile shall be within the ranges given in Section 2.4. Other methods of determining profile may be used if mutually agreeable between the contracting parties.

4.4 PARTICLE SIZE DISTRIBUTION

4.4.1 The abrasive supplier shall designate range(s) for maximum and minimum retention of each sieve size to meet the profile range(s) specified in Section 2.4 and determined in Section 4.3. The particle size distribution shall be measured in accordance with ASTM C-136 using the following U.S. standard sieves: 6, 8, 12, 16, 20, 30, 40, 50, 70, 100, 140, and 200. Upon request, the supplier shall substantiate that the specified size range will meet the required profile range. (See Note 7.6.)

4.4.2 The designated sieve size distribution and ranges will become the acceptance standard for the specific abrasive submitted (see Section 5.4).

4.5 HEALTH AND SAFETY REQUIREMENTS

4.5.1 The abrasive material as supplied shall comply with all applicable Federal, State, and Local regulations (see Note 7.7).

4.5.2 The manufacturer shall provide the purchaser with sufficiently detailed chemical analyses to allow the user to provide the protective engineering and administrative controls for blast cleaning identified in Federal, State, and Local codes.

4.5.3 Material Safety Data Sheets shall be furnished for all abrasive materials supplied.

4.6 OTHER REQUIREMENTS

4.6.1 In addition to the requirements of Sections 4.1 through 4.5, the specifier may also stipulate performance tests to establish abrasive consumption rate, cleaning rate, and abrasive breakdown. As there are currently no standards for these tests, they are not a part of this specification. However, upon mutual agreement between supplier and purchaser, a performance test procedure can be established. Appendix A outlines a suggested procedure.

5. Qualification Testing and Conformance Testing

5.1 RESPONSIBILITIES FOR TESTING

The procurement documents should establish the specific responsibilities for qualification testing and conformance testing. Unless otherwise specified, the supplier is responsible for performing and documenting the tests and inspections called for in this specification.

5.2 CLASSIFICATION OF TESTING

The tests given in Section 4 are classified as qualification tests or conformance tests, as defined below.

5.2.1 Qualification tests are those tests which are run to initially qualify a material for this specification. Qualification tests are also required whenever a significant change has occurred in the source, method of processing, method of shipping or handling of the abrasives. The qualification tests include all the tests in Sections 4.1 through 4.6.

5.2.2 Conformance tests are those tests which are performed to verify that the material being submitted has the same properties as the material which initially qualified. Conformance tests shall be conducted on each lot as required by the purchaser. The frequency and lot size for quality conformance testing shall be mutually agreed upon between the supplier and the purchaser. The required conformance tests are particle size distribution (Section 4.4), water soluble contaminants (Section 4.1.4), moisture content (Section 4.1.5) and oil content (Section 4.1.6).

5.3 METHODS OF SAMPLING

5.3.1 Sampling for Qualification Tests

5.3.1.1 **Bagged Abrasive.** Three or more sacks of abrasive shall be randomly selected from each inspection lot. The sacks shall be mixed and separated and a 50 kilogram (kg) (110 Lb) composite sample prepared in accordance with ASTM C-702.

5.3.1.2 **Bulk Abrasive.** A 50 kg (110 lb) composite sample shall be obtained from the blended finished product in accordance with ASTM D-75. (See Note 7.8.)

5.3.2 Sampling for Conformance Tests

5.3.2.1 **Bagged Abrasive.** One sack of abrasive shall be randomly selected from each inspection lot and a 2 kg (4 Lb) composite sample prepared in accordance with ASTM C-702.

5.3.2.2 **Bulk Abrasive.** A 2 kg (4 lb) composite sample shall be obtained from the blended finished product in accordance with ASTM D-75.

5.3.3 Other methods of sampling may be used if mutually agreeable between the contracting parties.

5.4 DOCUMENTATION OF INSPECTION AND TESTING

The supplier shall furnish all documentation required to verify that he has completed the requirements of the qualification tests and conformance tests specified. At a minimum, the documentation shall include the following:

5.4.1 **List of tests performed.** This list shall include the title of the test, the appropriate standards used, any deviation from standard practice, and the numerical results of the testing.

5.4.2 **Testing facilities.** The documentation of facilities shall include the name and location of the laboratory, the re-

sponsible laboratory official, and laboratory certification or other evidence of qualification.

5.4.3 **Date of testing.** This shall include the date of original qualification (if applicable) and dates of completion and official approval of testing results.

5.4.4 **Affidavit.** The procurement documents should establish the responsibility for any required affidavit certifying compliance with this specification.

5.5 FREQUENCY OF TESTING AND INSPECTION

All materials supplied under this specification shall be subject to timely inspection by the purchaser or his authorized representative. The frequency and lot size of inspection shall be established by mutual agreement between the supplier and the purchaser.

5.6 APPROVAL

The purchaser shall have the right to reject any material supplied which is found to be defective under this specification. In case of dispute, the arbitration or settlement procedure, if any, established in the procurement documents shall be followed. If no arbitration procedure is established, the procedures specified by the American Arbitration Association shall be used.

6. Disclaimer

6.1 While every precaution is taken to insure that all information furnished in SSPC specifications is as accurate, complete, and useful as possible, the SSPC cannot assume responsibility nor incur any obligation resulting from the use of any materials or methods specified therein, or of the specification itself.

7. Notes*

7.1 Reclaimed abrasive may not meet the requirements of this specification because of particle degradation and retained contaminants. To confirm compliance, reclaimed abrasive shall be retested.

7.2 Materials furnished under this specification which produce the required surface profile under standard test conditions may produce a different surface profile depending upon job condition, type of surface, blasting pressure, etc.

7.3 The limitation for abrasive conductivity is based on pressure immersion testing and accelerated outdoor exposure tests performed by SSPC and the National Shipbuilding Research Program.

7.4 Users of abrasives containing quartz (crystalline silica) should comply with the requirements of ASTM E-1132.

7.5 Methods A and B of ASTM D-4417 or National Association of Corrosion Engineers RP-02-87, "Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Using Replica Tape" may also be specified by agreement between purchaser and supplier.

7.6 SSPC will maintain a list of abrasives and sieve sizes for which data on profile and other specified tests have been submitted. The data will not be verified by SSPC, but will be furnished upon request to those wishing to use this specification. It is anticipated that at a future date, specific size designations for individual abrasives will be incorporated into this or another SSPC specification.

7.7 Disposal of abrasives should be in compliance with all applicable Federal, State, and local regulations. It is noted that the spent abrasive may contain hazardous paint and other foreign matter.

7.8 The importance of properly obtaining a sample cannot be over-emphasized. All subsequent analyses performed on the selected sample are likely to be affected by particle size, so it is imperative that every reasonable effort be made to select the sample in a way that will assure proper representation. Therefore, it is important to select the proper sampling location, and to use proper techniques to select the sample.

The following guidelines should be kept in mind when deciding on a sampling method:

7.8.1 If possible, sample the material to be tested when it is in motion, in such places as a conveyor output point or a chute discharge.

7.8.2 The whole of the material stream should be taken for many short periods of time in preference to part of the material stream being taken for the whole of the time.

*Notes are not requirements of this specification.

Appendix A. Optional Test To Determine Rates of Surface Cleaning by Abrasives and of Abrasive Consumption*

A.1 TEST PROCEDURE

A.1.1 For testing purposes hot rolled carbon steel plates or other flat structural steel with surface area of 20 to 80 sq. ft. (1.9 to 7.4 m^2) shall be abrasive blast cleaned to a SSPC-SP 10 "Near White" condition. Surface profile shall range from 2.0 to 3.0 mils (51 to 76 microns) when measured by replica tape (ASTM D-4417, Method C). These panels shall be coated within 4 hours of abrasive blasting, or before surface rusting is visible — whichever occurs first.

A.1.2 The panels prepared in A.1.1 shall be coated with three coats of epoxy-polyamide paint (total DFT 7-10 mils [178-254 microns]) conforming to MIL-P-24441 or other standard reference painting system agreed to by the contracting parties. The panels shall be cured for a minimum of seven days at a minimum temperature of 70° F (21°C). Following curing, the panels shall be marked in such a manner as to form a grid of squares, each being 1 sq. ft. (0.09 m^2) in area. Each plate shall contain a minimum of 20 squares.

A.1.3 Each abrasive type and size selected shall be tested using a 3/8 inch (9.6 mm) venturi nozzle operated at 95 ± 5 psig (655 ± 35 kilopascals) at the nozzle. A 600 lb pot shall be charged with 500 lbs (227 kg) of abrasive and the test

panel blasted to SSPC-SP 10 near-white condition. Each trial shall cover approximately 20 sq. ft. (2 m^2) of surface area. The blast pot shall be disconnected and weighed before and after each blast trial, and the following data recorded: start weight, finish weight, weight of abrasive used, square footage blasted, and time required to blast.

A.2 ABRASIVE CONSUMPTION RATE

The abrasive consumption rate shall be determined as the weight of abrasive used divided by the area cleaned, and reported in lbs of abrasive per square foot (kg per m^2).

A.3 SURFACE CLEANING RATE

The surface cleaning rate shall be determined as the area cleaned divided by the time required to blast and reported in square feet (square meters) cleaned per hour.

*The Appendix is not a requirement of this specification.

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